Final Technical Report

Project Title: Deepwater Subsea Pressure Compensated Chemical Reservoir (RPSEA project 11121-5302-01)

2016-07-10

SMT - The SMarT Solution™

Enabling long-distance subsea tie-backs

- 3000 BBL chemical storage & injection (eliminate chemical umbilical)
- Subsea pig launcher (eliminate 2nd flowline)

Platform for enabling Brownfield EOR

- Seafloor placement of 'kit' enabling shuttle to – from surface for IRM

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A non-compensated advisory group consisting of 50+ Subject Matter Experts (SMEs) representing 40+ stakeholder organizations volunteered and contributed their expert advice. All freely provided input and guidance when contacted via telephone and email in addition to participating in numerous meetings and surveys. (See section 11.1)

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Executive Summary

Ultra-deepwater floating systems routinely cost multiple billions USD and require multiple appraisal wells at costs in the hundred million range (each) to justify sanction, then years of delayed production while designing, constructing and installing the required facilities. According to numerous industry forecasts a growing number of oil and gas accumulations in deepwater will be developed via long tie-backs to existing host facilities. While individually these accumulations may be small in comparison to mega developments, in aggregate and particularly in the Gulf of Mexico, they could represent significant reserve and production growth. One of the key challenges to the success of these tie-backs is to safely and reliably supply the necessary wellbore chemicals and maintain flow assurance in the long distance flowline.

In today's low product price environment there is an even greater need to develop and commercialize a game-changing (low cost) solution to inject required chemicals at the point of consumption in long-offset subsea wells from both enabling and enhancing perspectives. The Safe Marine Transfer (SMT) project has addressed this pressing industry need by developing a qualified system design to safely deploy and reliably operate a 3,000 BBL chemical storage and injection system on the seafloor at or near the well site / point of use.

Current subsea umbilicals cannot flow the required volumes of high viscosity chemicals over significant offset distances and still have sufficient pressure to inject into high pressure subsea wells; hence the enabling nature of the SMT offering. From an enhancing perspective, SMT's low cost solution will help ensure financial viability of development of offset reservoirs in a low product price environment.

The SMT system as shown in Figure 1 consists of a barge (referred to as the Shuttle) with a dual barrier bladder storage system embedded within and a chemical injection system mounted on top, each consisting of Common off the Shelf (COTS) components.

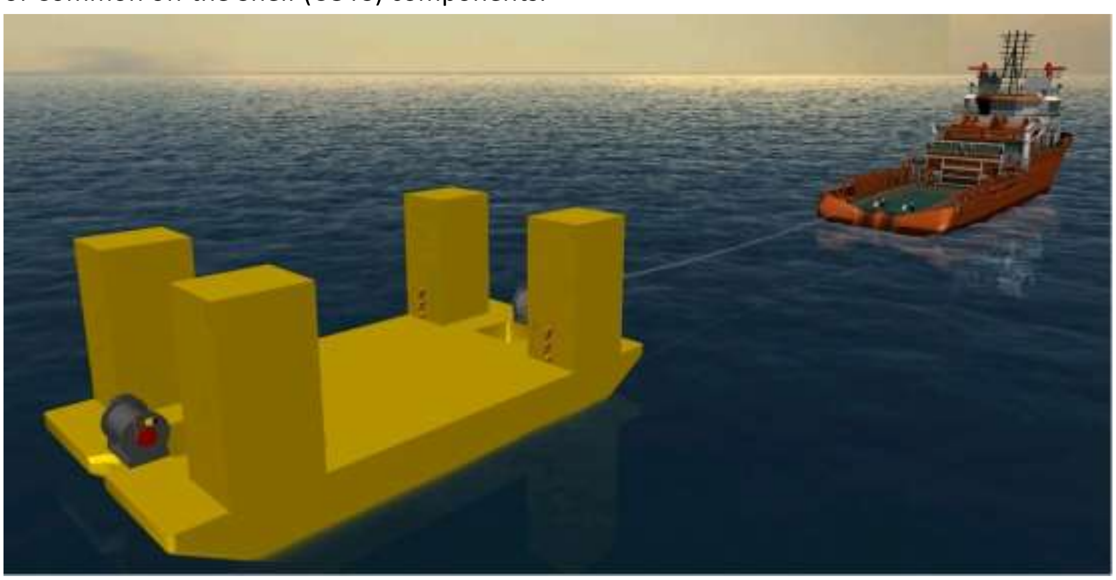


Figure 1: Shuttle Under tow to deepwater location

The shuttle is an extension of designs for currently certified and commonly utilized double hull hazardous chemical transport barge. Uniquely, the SMT Shuttle does have composite cylinders at the four corners to provide the entire system with positive buoyancy while submerged. The cylinders are U.S. Department of Transportation (DOT) certified and have been in common use for a decade, hauling Compressed Natural Gas (CNG) over public roads. For the SMT design, the cylinders will be filled with nitrogen and are rated for 5,000 feet (design), and conceptually to 10,000 feet subsea.

Bladders have been used for multiple decades to store large volumes of a variety of liquids in remote / harsh environments. Project screening tests for compatibility and durability show good results to date for the more common production chemicals. Most importantly, SMT and contractors have developed a design to safely and reliably deploy (ballast and submerge to ocean bottom) and recover (de-ballast) the entire Shuttle system utilizing lower cost (than conventional heavy-lift derrick barges) commonly available Anchor Handling Tugs (AHTs). The savings in direct cost (day-rate) and availability (mob and de-mob) versus a traditional heavy lift vessel is staggering and will have numerous other potential applications.

Two full Qualitative Risk Assessment (QRA) workshops with over 50 Subject Matter Experts (SME) who span the value chain have validated the concepts and determined no insurmountable challenges (based on Stage 1 level of analysis) and no technical barriers were identified that are not manageable. The shuttle design was refined in Stage 2 and two Design level FMEAs were performed. One evaluated the shuttle, its design and operations and the second DFMECA focused on the storage, injection and control systems. Both workshops were well attended by Industry SMEs resulting in an overall review of the design. The workshops identified/confirmed key risks which are readily manageable.

A Project side benefit is the potential for the robust shuttle to be used for deployment of other subsea facilities in addition to the primary chemical storage and injection system. This prototype design has capacity to safely transport ~600 tons of facilities to the seafloor. SMT believes this may become a game-changing installation methodology that may impact the future of subsea facility architecture.

Another important potential application for the shuttle is emergency response / well control support. The shuttle can deliver and inject dispersant at the seabed or deliver and support other seabed equipment.

There is further work beyond the original work scope that when performed will continue to advance the system's maturity level. Some of these work tasks are defined in the Section titled "Potential Next Steps."

Not only have the technical goals of the SMT project been met, but the financial goals have also been achieved. Cost share has graciously been contributed from a wide range of stakeholders, and the team is ready to move forward with RPSEA / NETL and our Industry partners in solving major energy challenges with a safe, reliable, and cost effective solution that is currently qualified to a Technology Readiness Level 4 (ready for site specific engineering, fabrication and deployment.)

Introduction

This Final Report summarizes the design and development work performed by Safe Marine Transfer (SMT) under the sponsorship of RPSEA's Deepwater Subsea Pressure Compensated Chemical Reservoir Project (RPSEA project 11121-5302-01). The work produced a qualified design to store and inject large volumes (3000+ bbls) of production chemicals subsea in a re-usable shuttle that can be deployed across a very wide range of conditions (design 5000 – readily extendable to 10,000 fsw). The concept is a design and build once – deploy multiple times and as such could be utilized as a chemical delivery service (opex) versus the conventional single use umbilical solution (capex). SMT is the concept developer and primary contractor. In addition to guidance and input from RPSEA and NETL, contracted work was provided by the following and as presented in Figure 2:

SHUTTLE

- Alan C. McClure Associates; Shuttle development, design & validation (CFD)
  - ABS; Approval in Principle
  - Hexagon Lincoln; buoyancy

SUBSEA CHEMICAL INJECTION UNIT (SCIU)

- Stress Engineering Services (Stage I – concept selection level)
- OceanWorks International, Inc. Detailed design and engineering

SUBSEA CHEMICAL STORAGE SYSTEM

- Avon Engineered Fabrics – Bladder manufacturer
  - Trelleborg Coated Systems US, Inc. – Elastomeric material manufacturer / supplier
- AIRE - Bladder manufacturer
  - Seaman Corporation; Plastic material manufacturer / supplier
- Baker Hughes Inc.; Production chemicals, test data, and expert guidance
- Inflection Consulting Inc.; Measurement and sensors
- Nalco Environmental Solutions LLC; Chemicals (dispersant)
- OceanWorks International, Inc.; Scale Model Test Apparatus
  - Star Precision; Fabricator – steel frame
  - Aquarium World; Assembler (including acrylic panels)
  - Oilfield Unlimited Enterprise, Inc.; Testing
- Southwest Research Institute; Design concept review

MARINE INSTALLATION; PLANING & RISK MITIGATION

- Helix Canyon Offshore (Marine Operations)
  - GRI Simulations Inc.; (Simulation Software)
  - DSA (Dynamic Analysis)

CONTRIBUTIONS IN THE FORM OF GENEROUS COSTSHARE

- DeepStar and its 60+ member companies
- ACMA
- Baker Hughes, Inc.
- Chitwood Engineering
- Energy Valley, Inc.
- Fugro
- GRI Simulations Inc.
- Helix Canyon Offshore
- Oilfield Unlimited Enterprise, Inc.
- SMT Advisory Committee – over 50 globally recognized Subject Matter Experts (SME)
- University of Houston

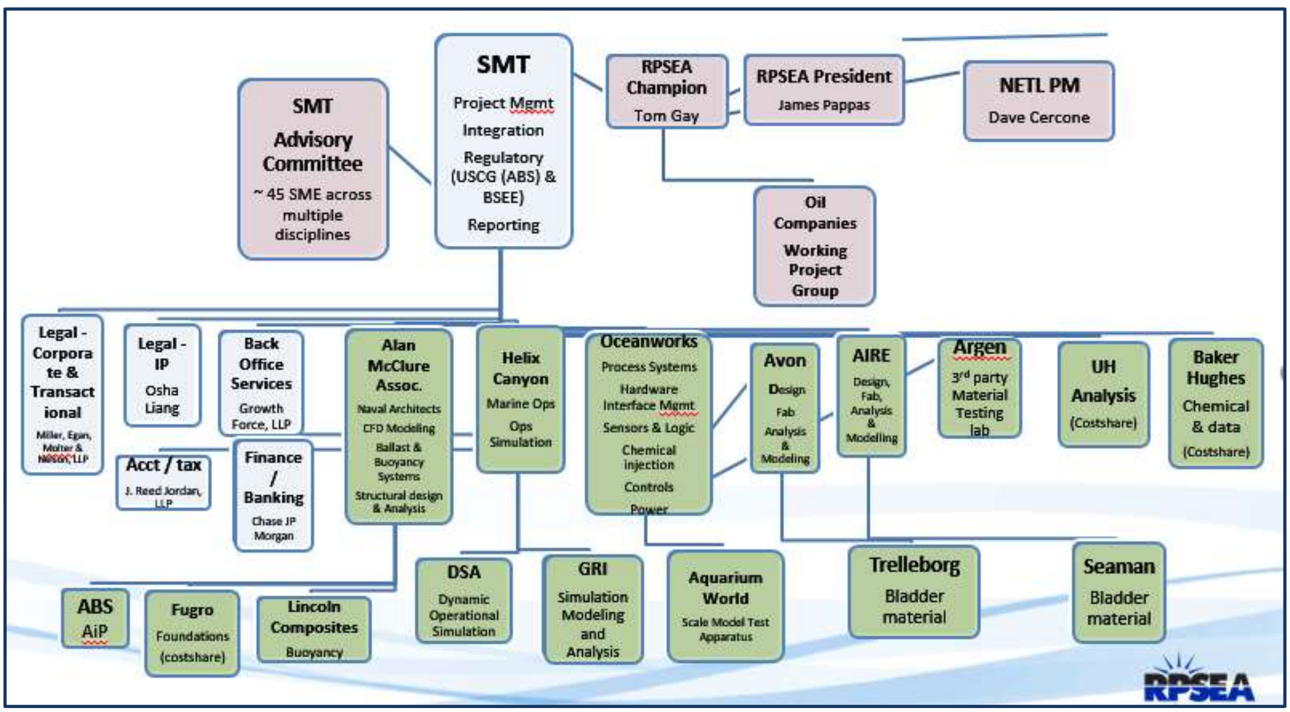


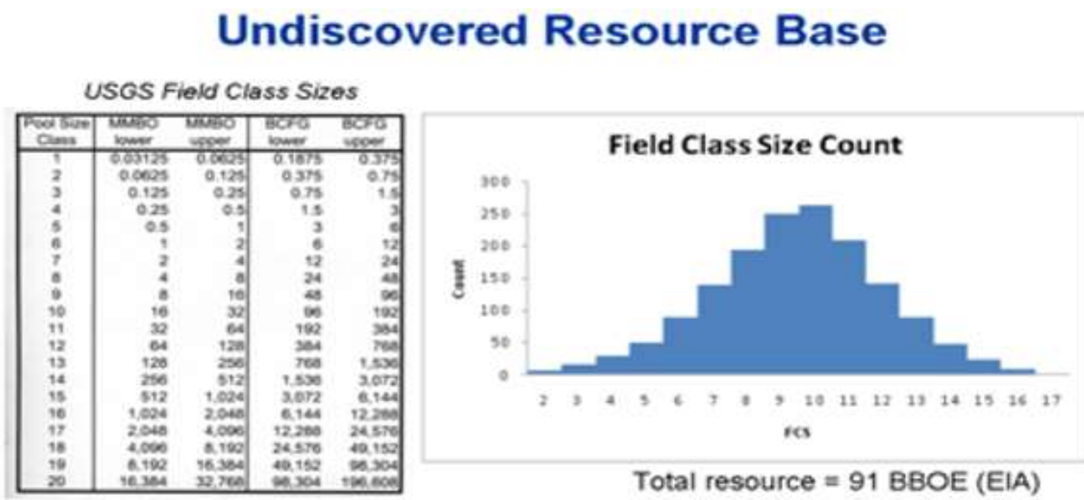
Figure 2: Safe Marine Transfer, LLC - project team

Working together, this world class team of designers, engineers, scientist and naval architects have conceptualized, designed, engineered, verified, and documented SMT's game changing technology. Attachment 2 provides a 'Master Document Register' of the many supporting documents and reports. While these were developed as part of the overall integrated project, for readability of the subject report, sensitivity of SMT confidential and proprietary IP, they are referenced with the over-arching findings summarized herein. It is the objective of this Project Report to document the high-level, significant findings and provide a technical 'umbrella' referencing the detailed support.

Value Proposition

Size of the prize; tie-back of long offset subsea wells

DOE's Energy Information Agency (EIA) has developed data (USGS; OFR-2007-1260, 2007) that shows that while 'small' fields are by definition small, the very large number of small fields can contribute significantly to the overall resource base, if they can be economically developed. Today, and looking forward it is most likely that many of these 'small' fields will be developed with subsea wells and tied back to production / surface hosts. (Figure 3).



Pool Size Class	MMBO lower	MMBO upper	BCFG lower	BCFG upper
1	0.03125	0.0625	0.1875	0.375
2	0.0625	0.125	0.375	0.75
3	0.125	0.25	0.75	1.5
4	0.25	0.5	1.5	3
5	0.5	1	3	6
6	1	2	6	12
7	2	4	12	24
8	4	8	24	48
9	8	16	48	96
10	16	32	96	192
11	32	64	192	384
12	64	128	384	768
13	128	256	768	1,536
14	256	512	1,536	3,072
15	512	1,024	3,072	6,144
16	1,024	2,048	6,144	12,288
17	2,048	4,096	12,288	24,576
18	4,096	8,192	24,576	49,152
19	8,192	16,384	49,152	98,304
20	16,384	32,768	98,304	196,608

Figure 3: Undiscovered resource base by field class size

Additionally, the National Subsea Research Initiative (NSRI) recently determined that an industry-wide approach could unlock in excess of 1 billion barrels of oil to give the North Sea a new lease of life. NSRI was tasked with helping to find the new, disruptive subsea technologies that could unlock these small discoveries and help prolong the life of the North Sea. "Solving the small pools challenge could yield a reward potentially greater than predicted with regards to the domestic market. It would enable the already capable UK supply chain to export its knowledge, products and services to international markets, thus safeguarding jobs, revenue and maximizing economic recovery from the North Sea," stated (Drummond, 2016)

Work done by Knowledge Reservoir, LLC funded by RPSEA and the DOE (Knowledge Reservoir, 2007) shows that 20% of the Original Oil In Place (OOIP) is contained in 80% of the number of reservoirs, meaning there are many small reservoirs containing the remaining oil (Figure 4). The clear takeaways;

1. There are a very larger number of smaller resource pools that in aggregate represent a significant resource
2. New game-changing technology and business practices will be required for cost effective development.

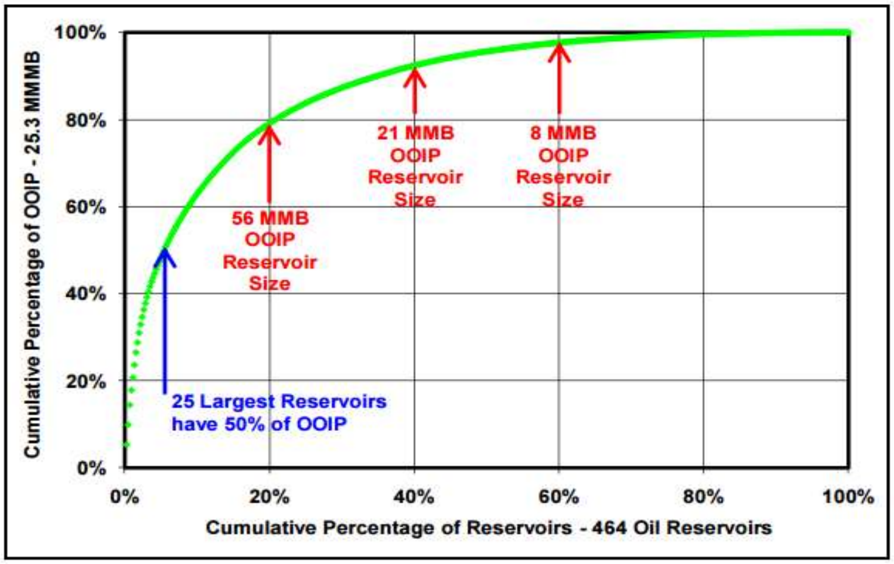


Figure 4: Cumulative % of Neogene OOIP vs. cumulative number of reservoirs

The business drivers for development of SMT's game-changing solution were to develop a safe and environmentally friendly method of supplying production chemicals to long offset subsea wells, too deep and too far offset to be supplied by umbilicals. Additionally, the technology has applications to supplement existing umbilical solutions which may be undersized due to 'missed' original estimates in well requirements, changing reservoir production characteristics and / or damaged / fouled / corroded / plugged tubes within an existing umbilical. The SMT solution can help enable development of smaller satellite fields that cannot bear the complexity, cost and operational risks associated with a traditional system. The solution may also enable early production from exploratory wells in advance of full field sanction when umbilical purchase and installation could be delayed until full field assessment and / or development is complete. Additionally, the technology could prove useful with support services for subsea construction, well intervention / spill response activities. See additional potential applications in Figure 5.

Brownfield Application Drivers

- Mechanical failure of an existing chemical injection umbilical.
- Insufficient capacity of an umbilical to deliver the required chemicals.
- Support for secondary reservoir recovery operations.

Greenfield Application Drivers

- Extreme satellite well offsets such that small umbilical lines are insufficient.
- Limited host deck load capacity for additional chemical equipment & storage.

Offshore Emergency Response

- Rapid transportation & deployment of large volumes of spill response chemicals with an efficient delivery system at the emergency site.

Construction / de-commissioning support

Well Intervention

Figure 5: Potential applications

The Challenges

Virtually all wells require various volumes and types of production chemistries during their operational life. This is particularly the case with subsea wells. Many flow assurance experts (Koh, 2015) (Volk, 2008) have declared hydrates to be the number one problem with flow assurance; they are costly to prevent and / or mitigate and pose safety concerns. Figure 6 is a photo of a hydrate plug being removed from a flowline. Of course in-situ deposition of paraffin and asphaltene, along with corrosion effects can also cause significant problems (See Figure 7).

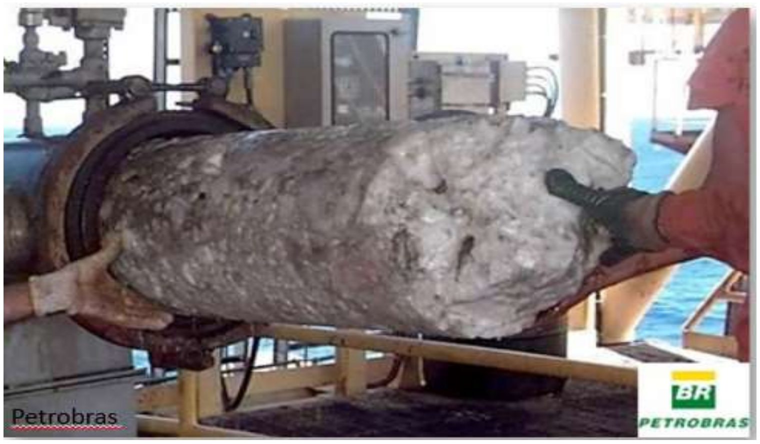


Figure 6: Hydrate plug removed from gas pipeline offshore Brazil, courtesy of Petrobras

Figure 7: Paraffin blockage

Onshore, chemical treatment companies frequently maintain local storage near the wellhead and can readily and at low cost refresh supplies via truck delivery. Offshore, the logistics / supply chain is much longer, more complex and costly. Starting at quayside, chemicals are loaded onto supply boats that then transport offshore to the destination platform. Then rigging is hooked up to the chemical containers and cranes are utilized to hoist on deck and position into place chemical transportation totes. Alternatively, in some situations hoses and pumps are utilized to transfer the chemicals from boat to platform deck. From the platform deck-based storage systems, chemicals are then pumped to point of consumption subsea via complex and expensive umbilicals. As reliable and constant supply of chemical often means the difference between production and shut-in wells, large stocks of chemicals are frequently kept on hand; taking up expensive platform space and creating additional personnel exposure risks. (See Figure 8.)

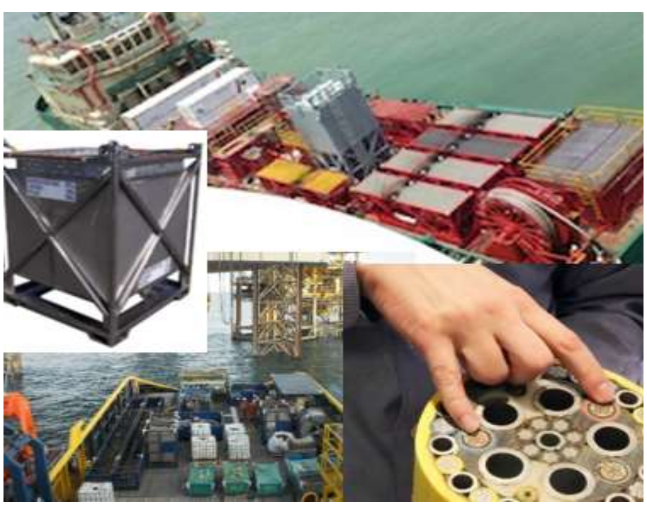


Figure 8: The journey of production chemicals from quayside to subsea wells

Table 1 below was constructed from actual deepwater Gulf of Mexico chemical consumption data graciously provided by Baker Hughes Inc. for seven ‘typical’ deepwater GOM fields. (Methanol, the largest chemical consumed by volume, is typically purchased in ‘neat’ form directly from wholesalers – and thus not shown on table.) The data supports and confirms DeepStar data (DeepStar, 2010) which highlights the need for large volume storage systems – thus, supporting the need to develop a large (3,000 bbl) system.

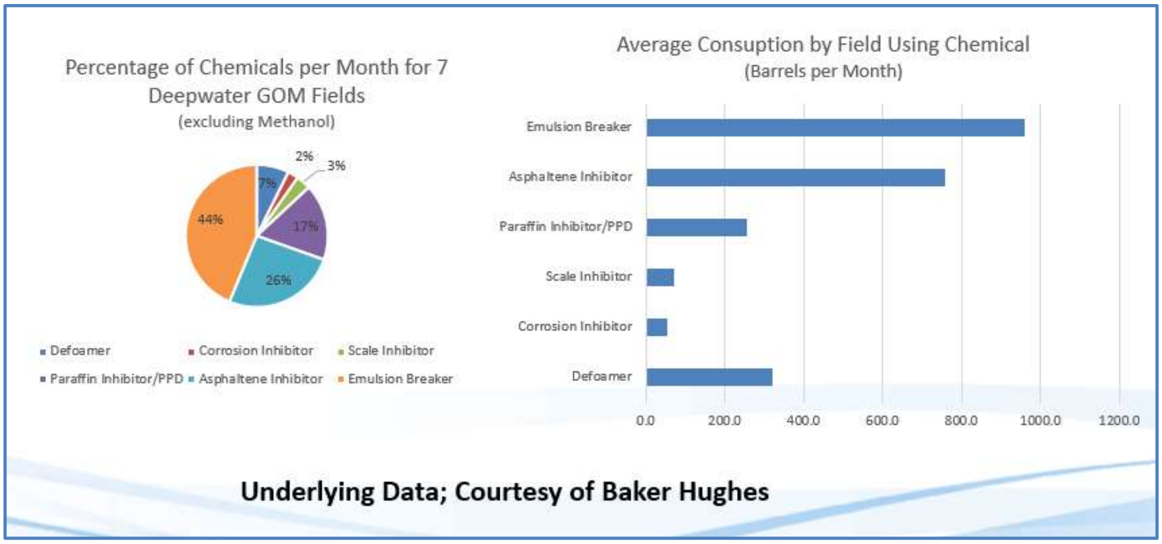


Table 1: Typical deepwater chemical use, Gulf of Mexico

The data also shows that some chemicals are utilized at a much lower dosage rate. An operator study conducted by SMT served to confirm these findings (Safe Marine Transfer, LLC, 2015). Conveniently / appropriately the SMT storage system can be scaled down for lower volume usage chemicals.

Additional, today we have a convergence of the technical challenges with economic / financial challenges as technology costs have exploded over the last decade (Figure 9). The current tie-back record for oil stands at 43 miles in shallow-water depths and 25 miles in deepwater (Dalmatian South to Petronius in 6,562 fsw) (Thomas, 2016) with just umbilical costs sometimes exceeding $1M per mile.

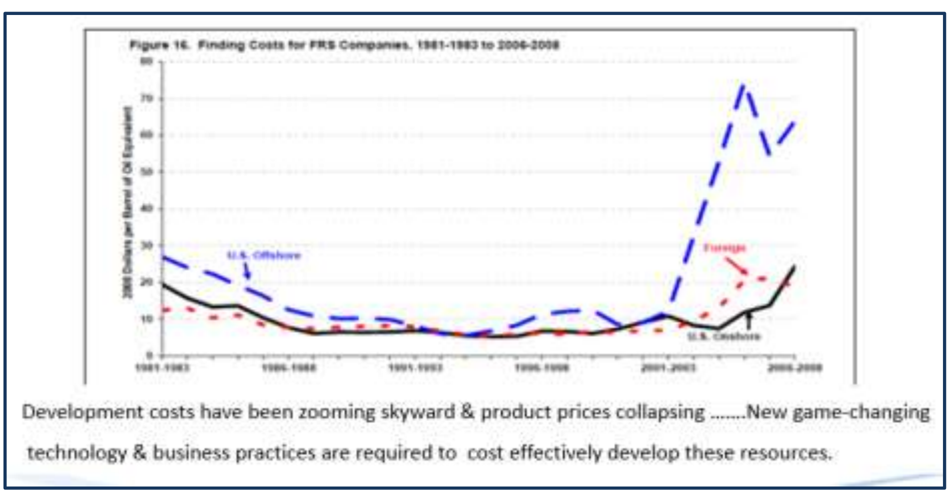


Figure 9: Financial situation will require 'game-changing' technologies

Design Basis

The Project design basis was agreed and documented during Stage I (Safe Marine transfer, LLC, 2014) and is summarized below.

Overall driving the project were the following design philosophies:

- Safety in all phases
- Incorporate a dual barrier storage philosophy.
- Flexibility in design – Adaptability & Re-use across wide range.
- Comply with existing design codes, classification rules & regs
- Maximize the use of existing and proven technologies.
  COTS – Commercially Available & Off-the-Shelf Technologies.
- Prototype design will be simplified to the minimum sufficient to demonstrate the technologies.

Design scenario:

- Application is a 6 well brownfield oil scenario where there is currently a 50% water cut with a relatively high saline content.
  - 3,000 bfpd / well – 1,500 bopd and 1,500 bwpd
  - SIWP - 5345 psia; FWP – 2826 psia.
- Location in the GOM Green Canyon area.
  - The installation site is essentially flat and within 1,000 ft of the drill center.
- MetOcean Conditions (based on DeepStar 11803 data).
- Water depth – 5,000 fsw
- Design life of the Shuttle – a minimum 10 year life that like other subsea structures may be extended with routine inspection. If justified, the shuttle may be recovered and periodically inspected with other process or payload IMR operations.
- Process and Storage Bladder Design Life is 10 years with a minimum operating life of 5 years for the bladders.

Met-ocean conditions:

- Based on DeepStar reports (DeepStar, 2011 - 2013).
- This extensive database (gigabytes) and lengthy report has been reduced to usable design information and criteria by Dr. Cortis Cooper whose contribution is appreciated (Cooper, 2014). Information includes:
  - Extreme Hurricane Events
  - Maximum 10-year Winter Storms
  - Extreme Loop Current Events
  - Topographical Rossby Waves
  - Temperatures
  - Operational Weather Conditions

Soils design basis:

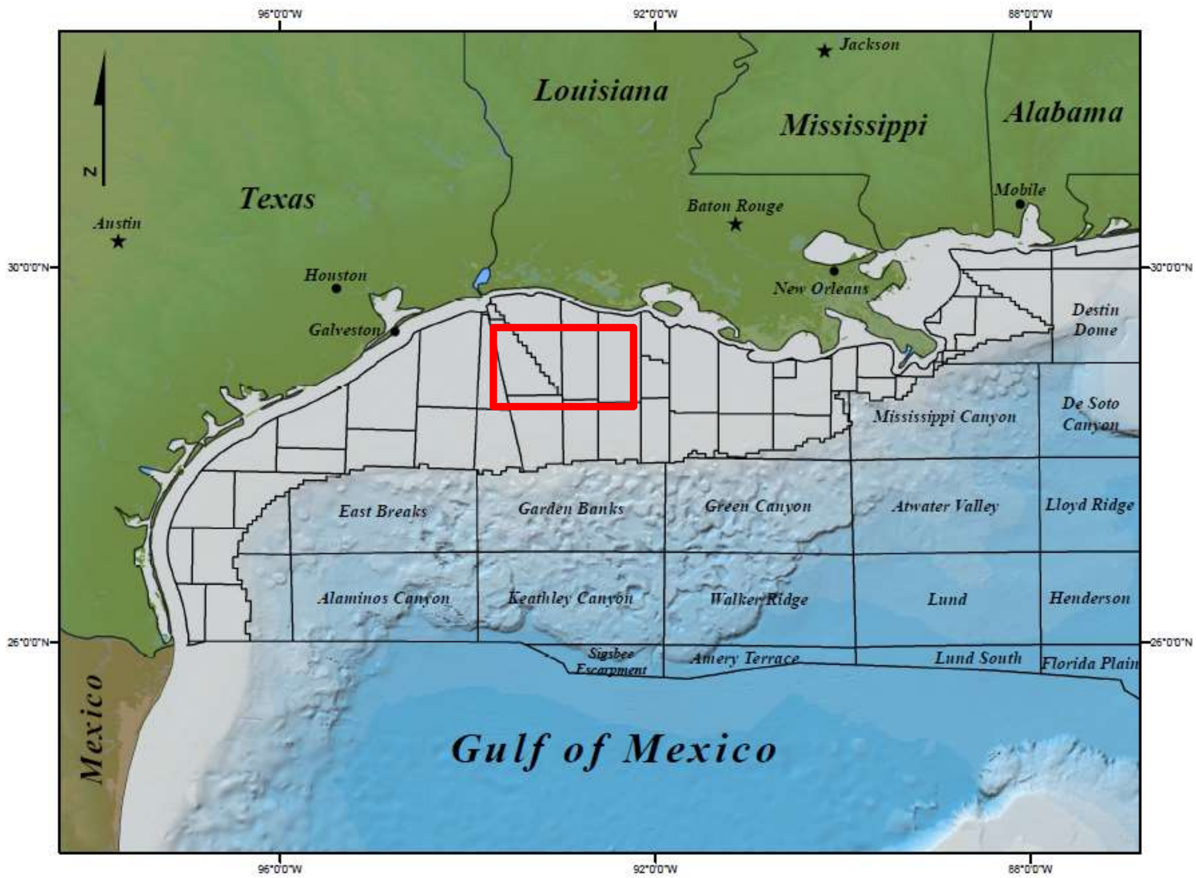


Figure 10: Project location - design basis

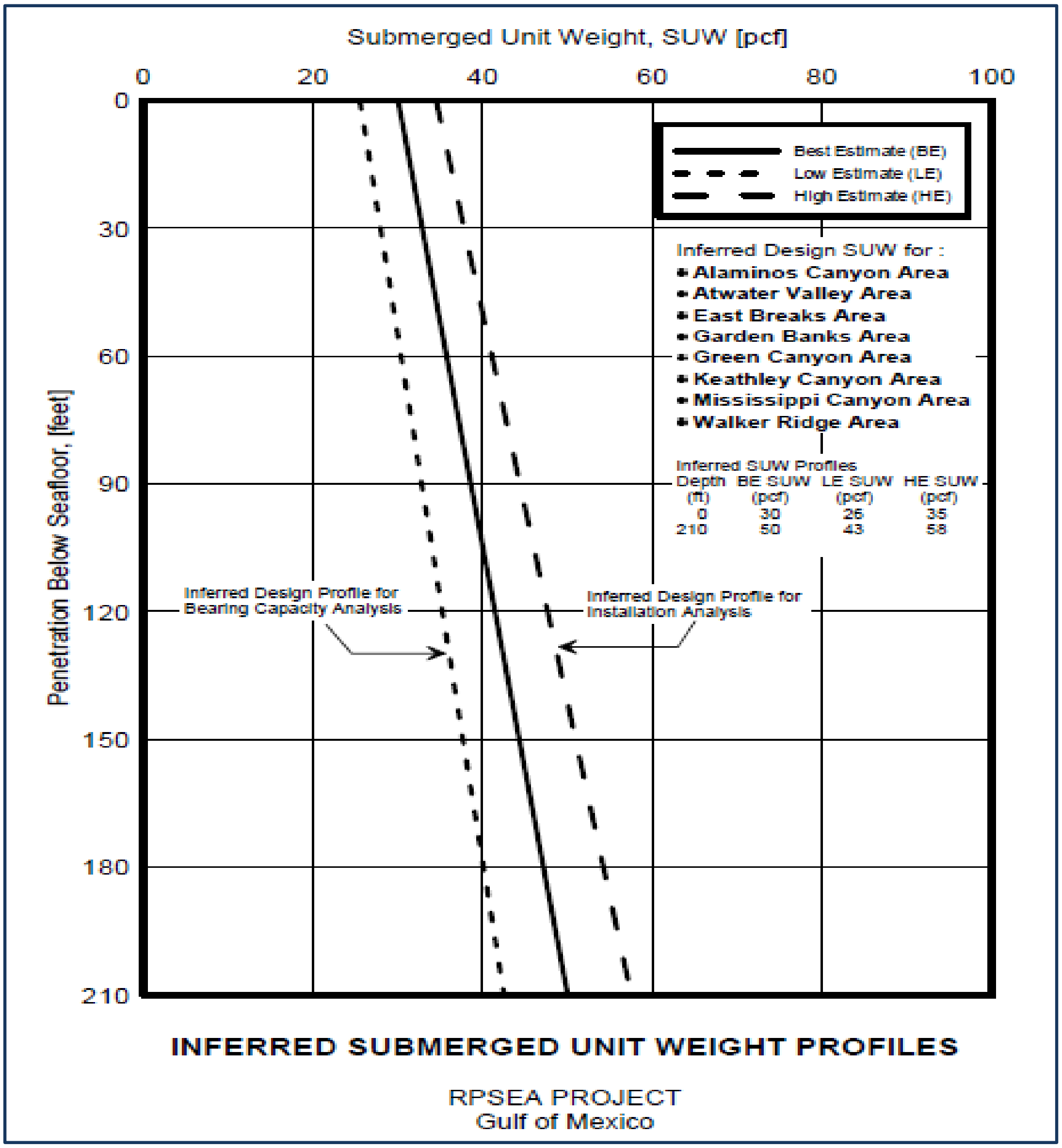


Figure 11: Example of soils information contributed by Fugro

Chemical types and rates:

There are two basic types of production chemical treatment scenarios:

1) High volume - batch treatment, such as when treating wells with methanol during transient conditions (start-up and shut-down) to mitigate the formation of hydrates.
2) Continuous injection - lower volumes, such as when treating wells with Low Dosage Hydrate Inhibitors (LDHIs) for hydrate mitigation, as well as many other ‘routine’ inhibitors: corrosion, asphaltene, paraffin, etc.

The choice of chemicals to inject depends upon the flow assurance strategy that best meets the production objectives of the field. SMT recognizes the impact these two injection strategies have upon the subsea injection system specification and design. Thus, both methodologies are included in the Basis of Design scenarios so that these most common practices can be deployed.

Methanol, LDHI, and asphaltene inhibitors represent the higher chemical injection rates and larger desired storage volumes. The 3,000 BBL storage capacities are appropriate for these chemicals. However, there are some chemicals, such as corrosion and scale inhibitors, that are injected at low rates and for these subsea storage capacities in the 200 to 500 BBL range provide adequate storage for most applications. These “small” tanks can be singularly installed with the use of workboat cranes (unlike the “large” tanks) and / or placed on the deck of the Shuttle. An important understanding is that SMT’s dual barrier concept and design principles ‘scale’ up and down and are applicable for both the large and small storage tank scenarios. These commonalities include chemical storage in dual barrier flexible bladders, chemical injection systems, instrumentation and control systems, and connection of power, control, and chemical jumper lines to the production systems. For the purpose of this RPSEA sponsored project, only development of the 3,000 BBL storage system is performed, while acknowledging that follow-on work to similarly develop small tank scenarios will be a straight-forward engineering effort.

The Solution

Concept Overview

The SMT concept (Safe Marine Technology, LLC, 2014) incorporates new (patented and patent pending) game-changing technology and business practices to deliver 3000+ barrels of production chemicals at point of need – subsea to 10,000 fsw delivered as a service and features:

- Robust and safe dual barrier chemical storage design with barrier fluid surrounding the internal chemical containing bladder. Chemical resistant bladder materials provide adaptability to handle any routine production chemicals with a storage capacity up to 3,000 BBL.
- On-board Chemical Injection Unit (CIU) that is adaptable to a wide range of injection rates and differential pressures with a design preference for utilizing COTS (Commercially available Off The Shelf) technologies and components.
- Shuttle (barge) transport and delivery system that may economically be recovered for maintenance / repair / chemical refresh and redeployed in other locations for continued service. It also readily and cost effectively facilitates equipment 'upgrades' to incorporate the latest technological advancements which can be done 'at the port' while refreshing chemical supply (versus subsea).

This section provides an overview with summary information on each system covered in the Stage II Task section of the report. Engineering details are then contained in the respective appendices. For an operational overview animation, please utilize the link below to the video:
https://www.youtube.com/watch?v=2ALyodkUg6c

Shuttle System

The Shuttle is basically a hazardous chemical Class barge that has been re-purposed for subsea installation. The Shuttle carries the payload; in this project the Subsea Chemical Storage System (SCSS) and Subsea Chemical Injection Unit (SCIU) – see figure 12. In other situations, the shuttle might carry large pumps, compressors, separation equipment, IOR kit, switch-gear / motor control center, etc. In the current configuration, the load might easily be in excess of 1,000 tons. ABS has reviewed the system and delivered their Approval in Principle (AiP).

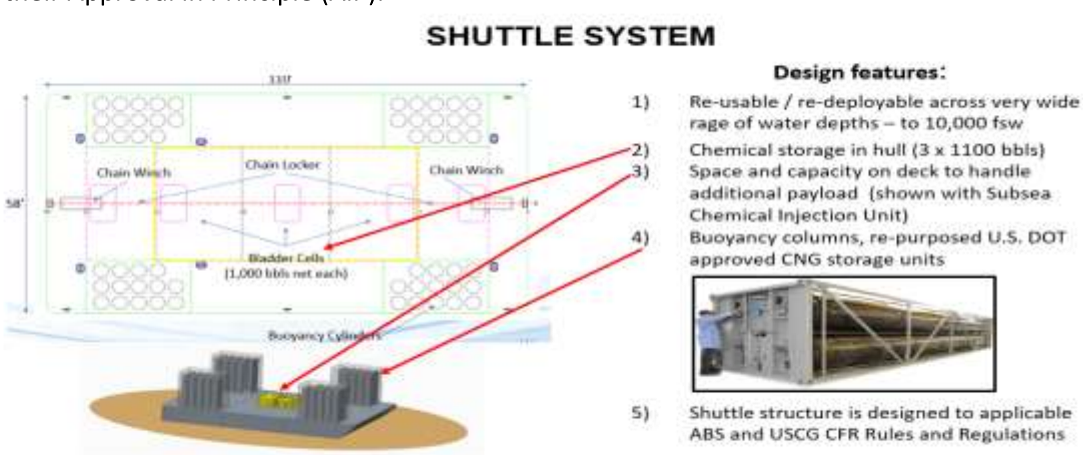


Figure 12: SMT Shuttle with Chemical Bladder Cells Embedded within Hull

Subsea Chemical Storage System (SCSS)

The SCSS has been designed to provide dual barriers for the chemicals intended to be delivered in accordance with both current and anticipated future regulatory requirements and industry practices. The SCSS utilizes heavy engineered fabric bladders that are similar to commercially available units that have been engineered and qualified for subsea chemical storage use. These bladders are within the sealed fixed volume of the Shuttle 'hold'. As the chemical is compressed during shuttle deployment and consumed during production operations, flow of seawater into the Hold provides for pressure compensation. Figure 13 presents an overview of the system.

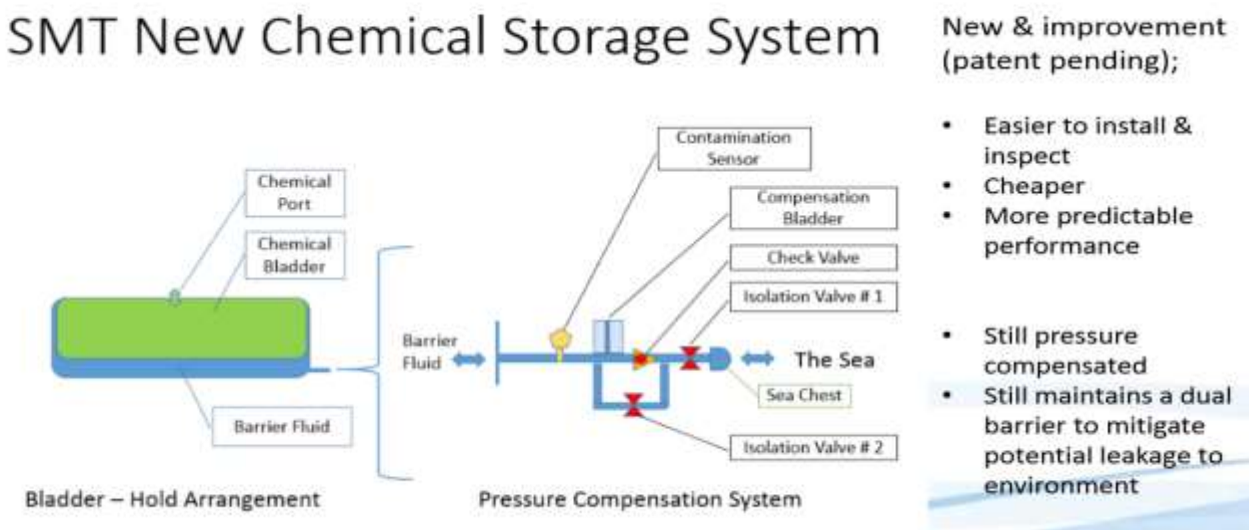


Figure 13: New dual barrier bladder innovation for Stage II

Three (3) SCSS are embedded within the Shuttle as shown in Figure 14. Smaller SCSS (for the lower consumption chemicals) could also be mounted on the shuttle deck and / or placed nearby on seafloor.

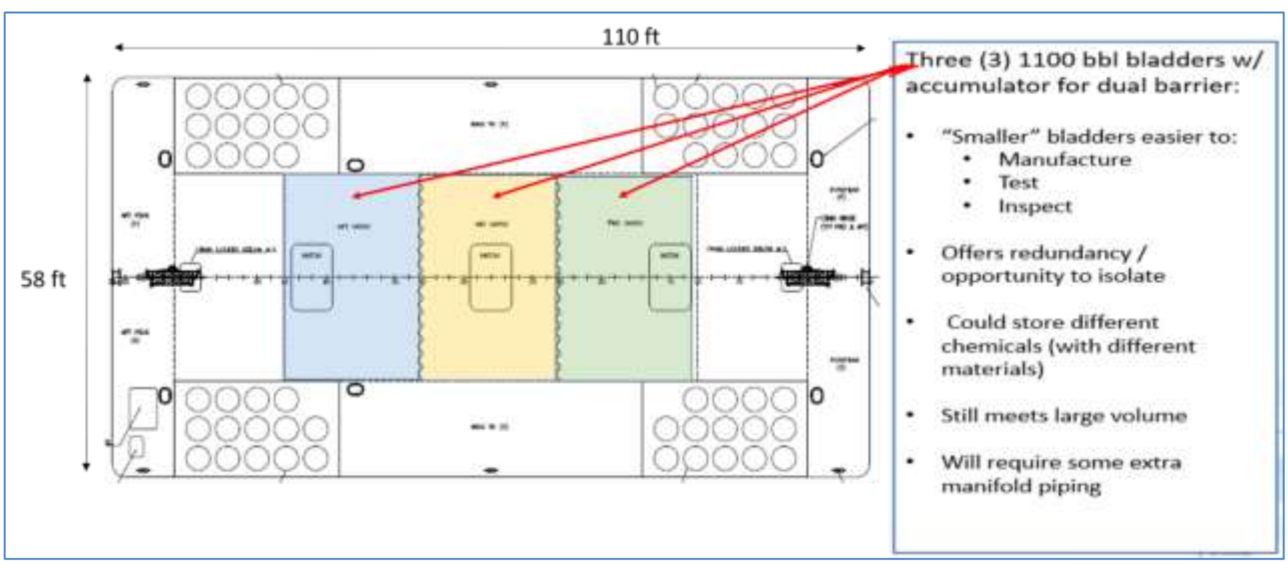
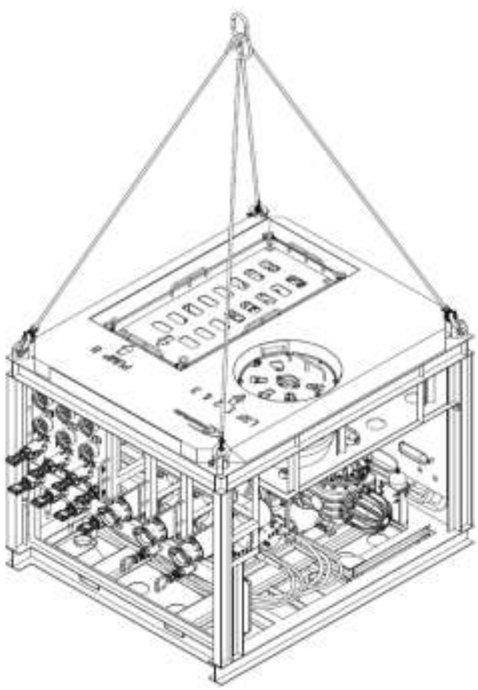


Figure 14: Three (3) 1100 barrel bladders offers more flexibility and better operability

Subsea Chemical Injection Units (SCIU)

The subsea chemical injection unit (SCIU) – Figure 15 is a small pump station mounted on a Shuttle which also houses the SCSS and is designed to operate submerged on the seafloor. This arrangement replaces the traditional approach of pumping the chemicals to the injection point over long distances, through expensive high-pressure umbilicals and eliminates host platform storage and load costs.

The SCIU receives electrical power and communications from the surface via an electrical umbilical on the seafloor. This can be from the existing umbilical that supplies power and communications to the nearby Christmas trees. The chemicals to be injected into the well are stored on-board the Shuttle in flexible bladders located in hold compartments on the shuttle. Flexible jumper hoses connect the chemical bladders to the on-board SCIU's. The SCIU's, and components within the SCIU that can be replaced for maintenance, are replaceable by ROV while the shuttle is subsea.



Summary dimensions and weights	
Weight (not to exceed)	30,000 lb.
Underwater weight (not to exceed)	26,100 lb.
Length	132 in.
Width	112 in.
Height, base to top of padeyes	102 in.
Hook height, for lifting by lifting bridle	250 in.

Figure 15: SCIU showing removable pump, filter packages, and CIMV's

After the Shuttle with its on-board SCIU's is submerged to the seafloor, the electrical umbilical and flying leads are connected, enabling chemical injection to multiple wellheads. Chemical injection then commences, controlled and monitored by the operator located on the surface asset at the surface end of the umbilical, typically a host such as a platform or floating production system (e.g. FPSO). The host can also be onshore facilities for some tie-backs to shore.

The heart of the SCIU is a marinized pump capable of pumping up to 10,000 psi at flow rates typically required for subsea chemical injection without umbilical flow constraints. Two types of systems are presented here: (1) short-term batch injection of methanol at shut-in well pressure, for injection above the Surface Controlled Subsea Safety Valve (SCSSV) and below the Christmas Tree after well shut-in, and (2) a continuous-injection system that pumps a lower flow rate of chemical at flowing well pressure, continuously for the design life of five years.

Most of the equipment on the SCIU's is existing subsea equipment, used without modification. A few items of hardware are high-TRL equipment that are currently used by the oil and gas industry for the same purpose, but whose marinization for subsea use is currently at TRL 2. Most notable among this latter category is the pump. The pump is at TRL 7 for topside pumping of these chemicals at the same flow rates and pressures. A program for testing the pump during an EFAT of the system is outlined in detail. The maturity of every component in the system is identified in a TRL-TRC analysis. Components and systems with less than TRL 7 are identified and the method for advancing that hardware to at least TRL 4 is presented.

This work demonstrates the feasibility and cost of the system, and documents the safety and operability of the system using detailed CONOPS, ICD, and DFMECA studies.

Marine Operations

SMT in concert with Helix Canyon Offshore developed a safe and efficient means to lower (deploy) and raise (recover) the Shuttle using a dual line catenary system with short segments of heavy chains that offset a positively buoyant Shuttle. This lowering system allows the use of significantly smaller support vessels on the surface and eliminates the risk of a single line failure from a single line lowering concept, which is associated with traditional heavy-lift barges. This system provides for weight control as the Shuttle is moved through the water column. It has been statically and dynamically analyzed at intervals during descent and ascent and found to be safe within the standard operating limits of the utilized systems (wire, boat displacement / operations, etc.) The 'story-board' presented in Figure 16 below provides an overview. Engineering analysis and computer modeling and simulation was done to further validate the concept. Computer modeling demonstrates that the installation / recovery methods effectively 'de-couple' the hook loads seen on the installation vessel from the ~ 1,000-ton shuttle system; thus allowing installation with low cost Vessels of Opportunity (VOO).

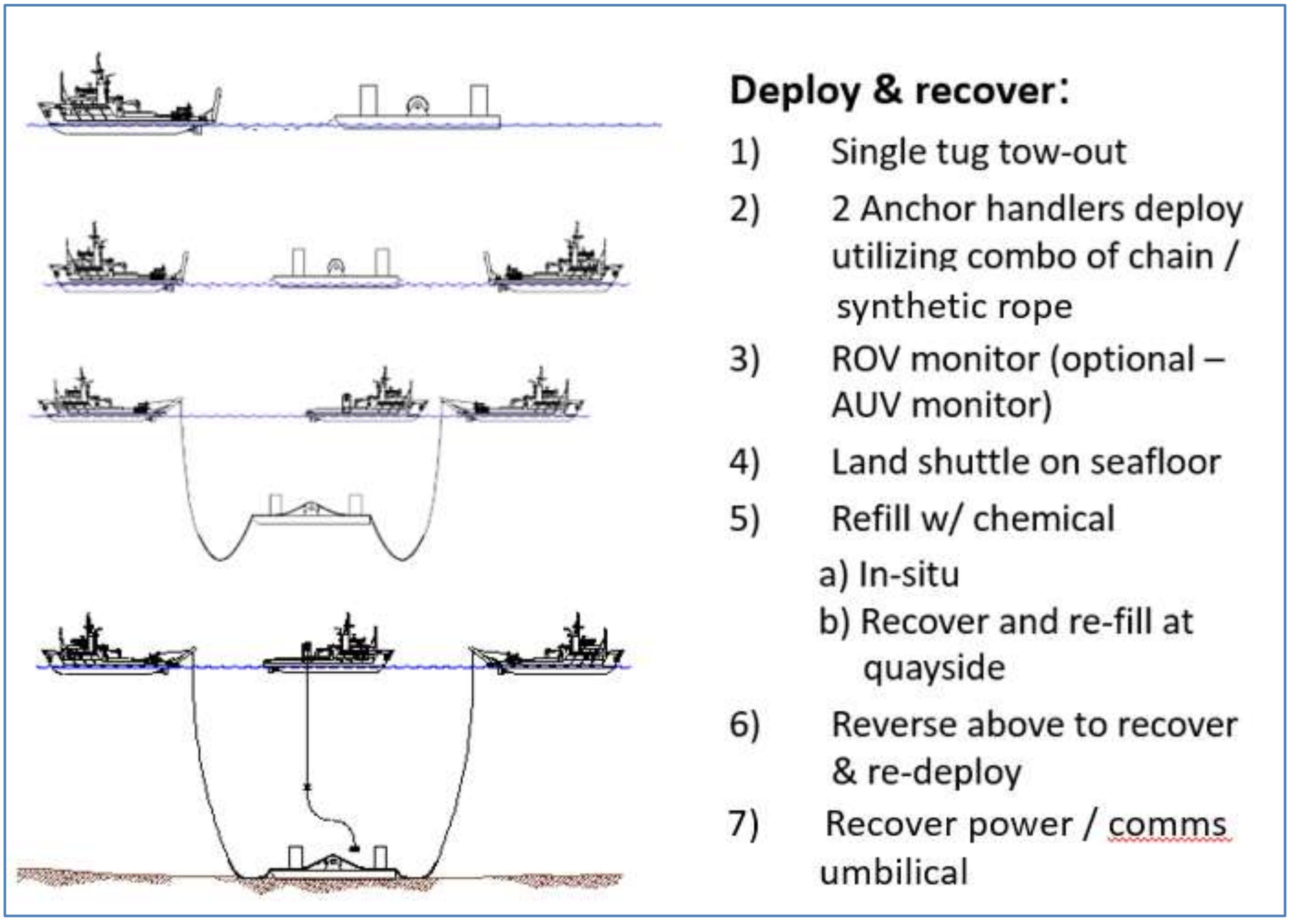


Figure 16: SMT's deployment method 'de-couples' the large mass of shuttle from surface vessels

Positive Shuttle buoyancy is provided via a system of composite CNG cylinders. Commercially available DOT certified units were identified as a 'proven' cost-effective solution. The system has been analyzed for use in this environment of high pressure (ambient – to 5000 fsw, extendable to 10,000 fsw) and low temperature. See Figure 17.

- Commercially available, hundreds in use for CNG service
- With a 3600 psig working pressure, 10000 psig test, the cylinder's internal pressure is set near hydrostatic pressure to improve its collapse resistance.
- Type IV DOT rated with stringent testing and inspection;
- Available in stock sizes for ISO containers
- Inexpensive (relatively!)

Figure 17: Light weight and robust composite CNG cylinders provide buoyancy

Figure 18 and 19 are screenshots of the video output of a mathematical simulation depicting tow out and through water column deployment respectively. Snippets of the video may be viewed at: http://youtu.be/Pz2GHHTV7ok

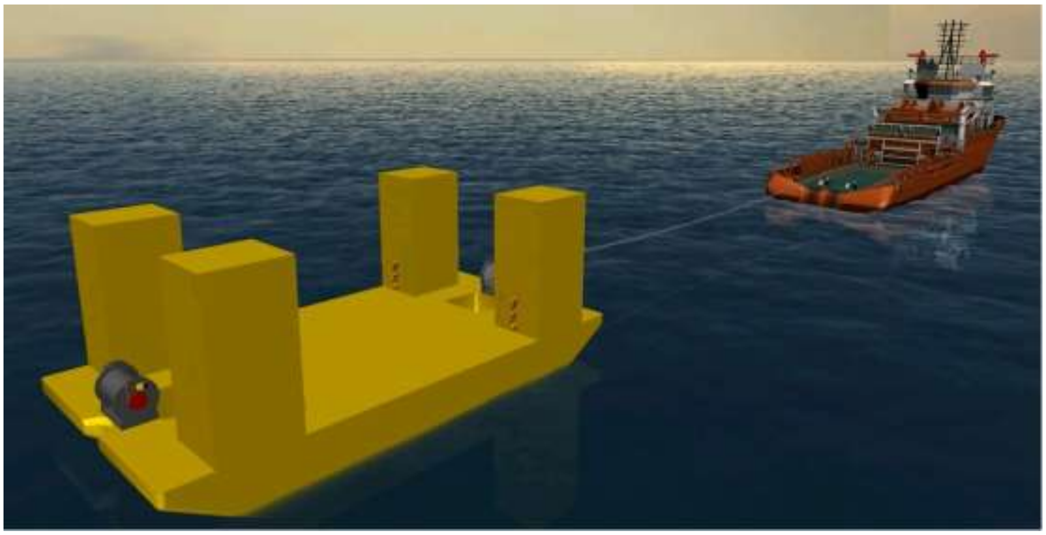


Figure 18: SMT Modified Standard Hazardous Chemical Transport Barge Being Towed to Location

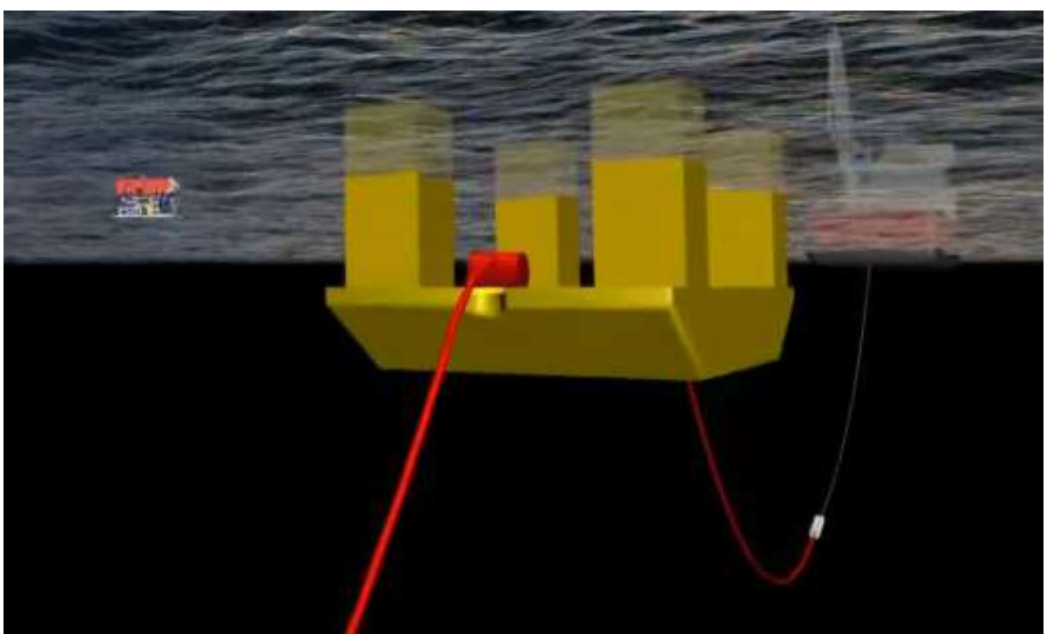


Figure 19: Shuttle being deployed through the water-column

Design Validation

A number of techniques were utilized to validate component, sub-system and total system performance.

Shuttle system:

- "Start" point; Hazardous chemical cargo barge design
- Commercially available composite cylinders – repurposed for buoyancy
- Engineering analysis
- Qualitative Risk Assessment (QRA) in Stage I with 2 dozen plus SMEs
- Computational Fluid Dynamics supplemented with empirical modeling
- DFMECA; reviewed with 2 dozen plus SMEs
- ABS AiP

Subsea Chemical Storage System (SCSS)

- "Start" point; DeepStar reports
- Proven material providers and bladder manufacturers leveraging military experience as well as other commercial solutions
- Reports and documentation of work from cost-share providers
- Engineering analysis
- Qualitative Risk Assessment (QRA) in Stage I with 2 dozen plus SMEs
- DFMECA; reviewed with 2 dozen plus SMEs
- Chemical – fabric 3rd party validation
- Scale Model Test Apparatus

Subsea Chemical Injection System (SCIU)

- "Start" point; DeepStar reports, with initial work by Stress Engineering Services
- "Leverage" through OceanWorks' expertise and previous work on similar systems
- Engineering analysis
- Qualitative Risk Assessment (QRA) in Stage I with 2 dozen plus SMEs
- DFMECA; reviewed with 2 dozen plus SMEs

Marine Operations

- "Leverage" through Helix / Canyon Offshore's expertise and previous work
- Engineering analysis
- Innovative thinking and patents filed (and issued)
- Qualitative Risk Assessment (QRA) in Stage I with 2 dozen plus SMEs
- DFMECA; reviewed with 2 dozen plus SMEs

Figures 20 and 21 provide visuals on some of the validation work performed.

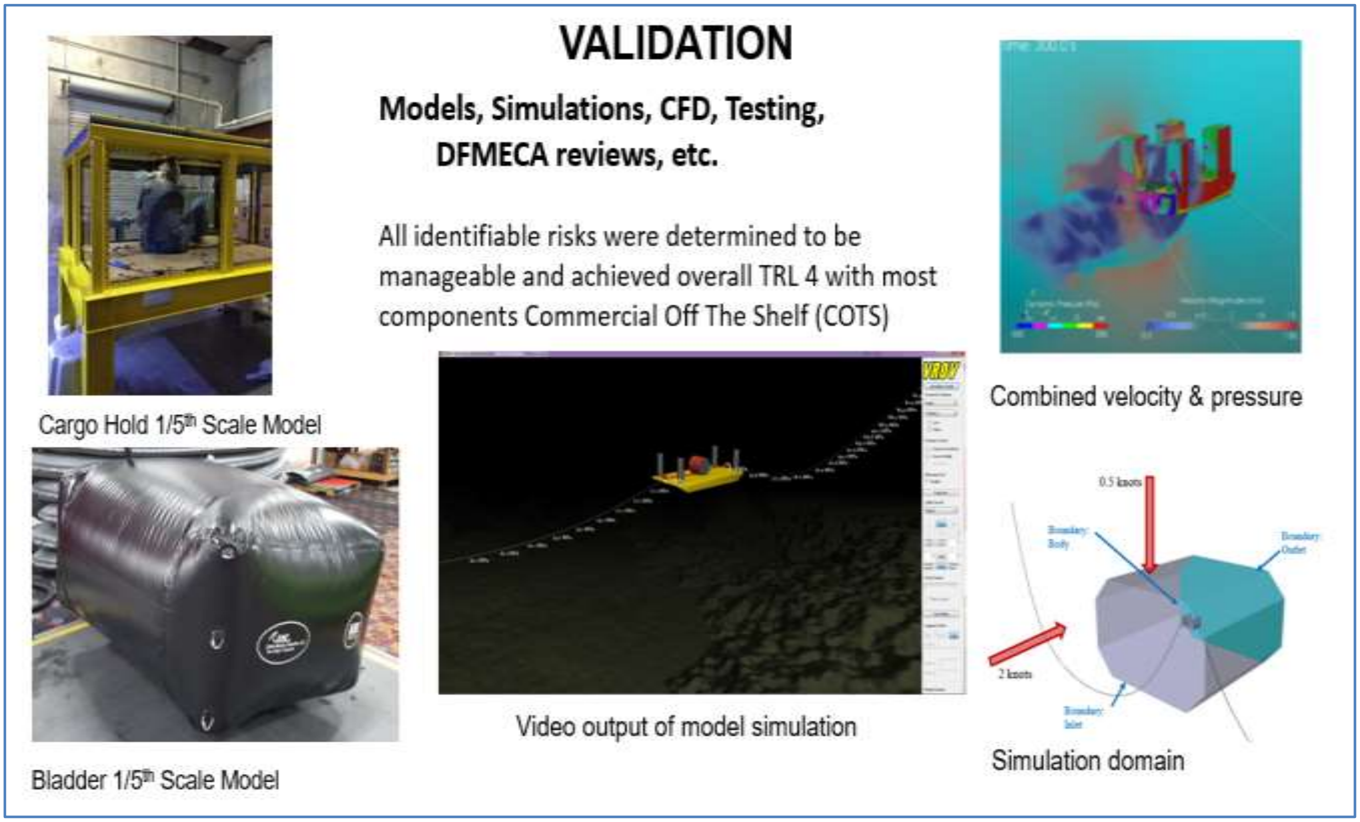


Figure 20: Shuttle validation with CFD and Scale Model Storage System testing

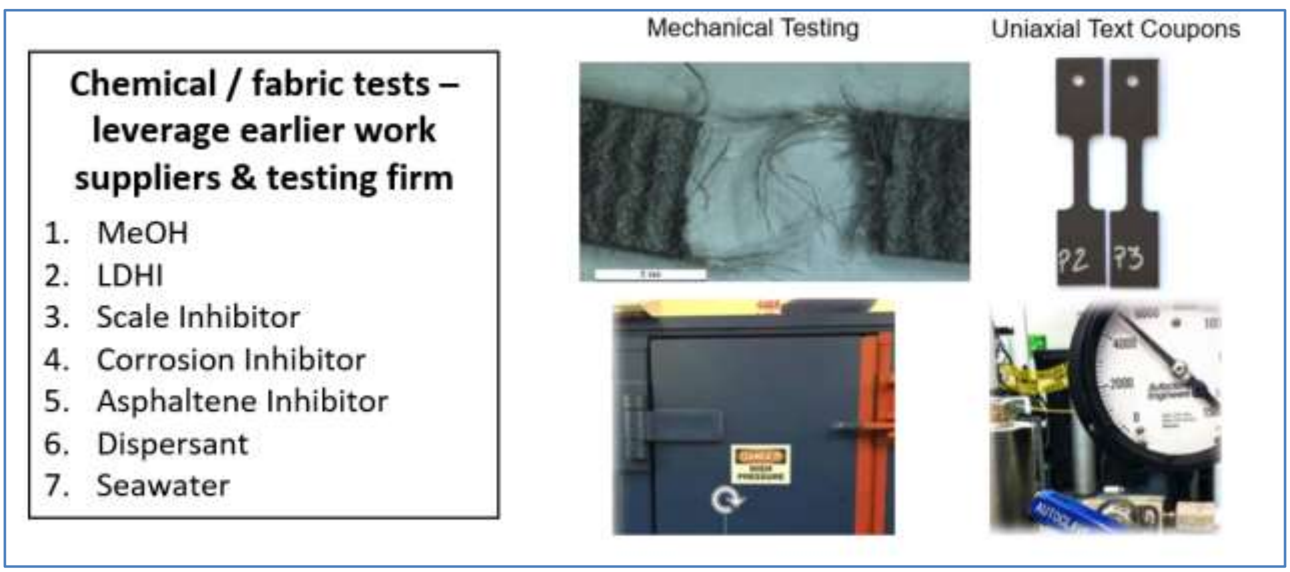


Figure 21: Manufacture formulation and testing - followed by 3rd party validation

As noted in the appendices, four (4) reports covering the overall validation were prepared;

- Two (2) were Qualitative Risks Assessments (QRA) in Stage 1 and
- Two (2) DFMECA near the end of the project. Summarized below is the overall approach with the DFMECAs.

Sown below in Figure 22 is an overall 'systems' interface diagram (original excel spreadsheet in appendices). Figures 23 and 24 depict the individual systems and interfaces.

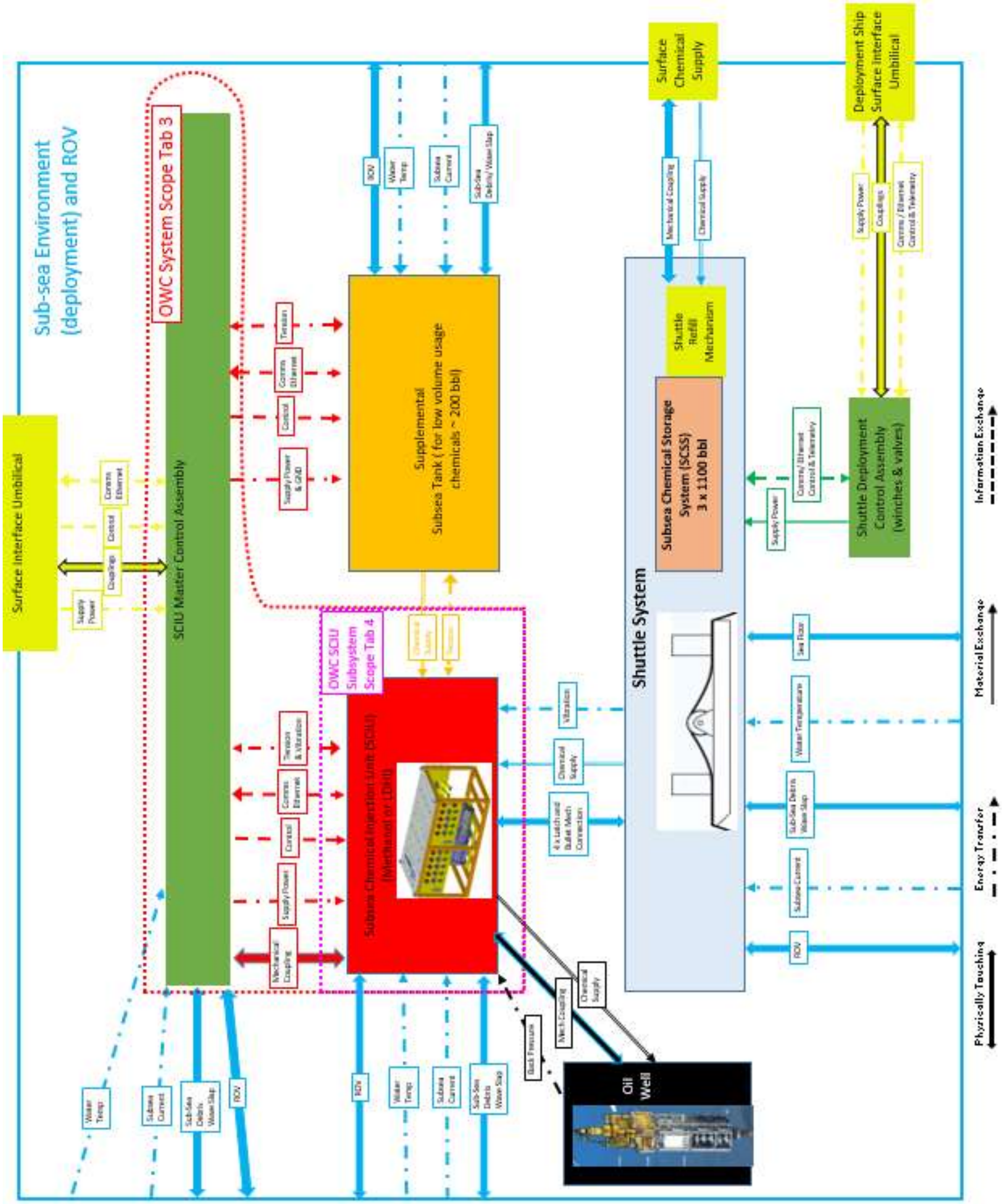


Figure 22: System interface overview

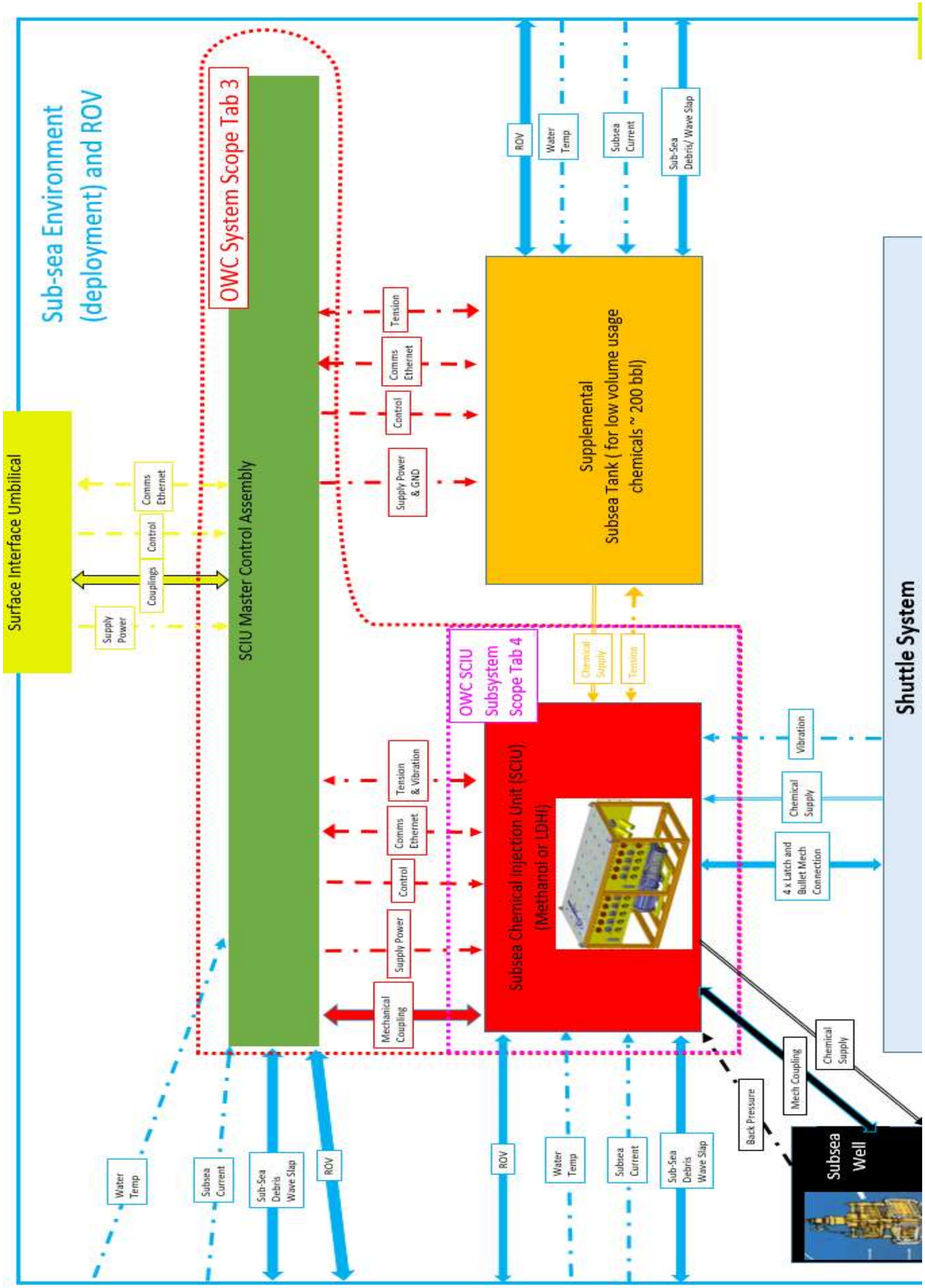


Figure 23: SCIU - interfaces

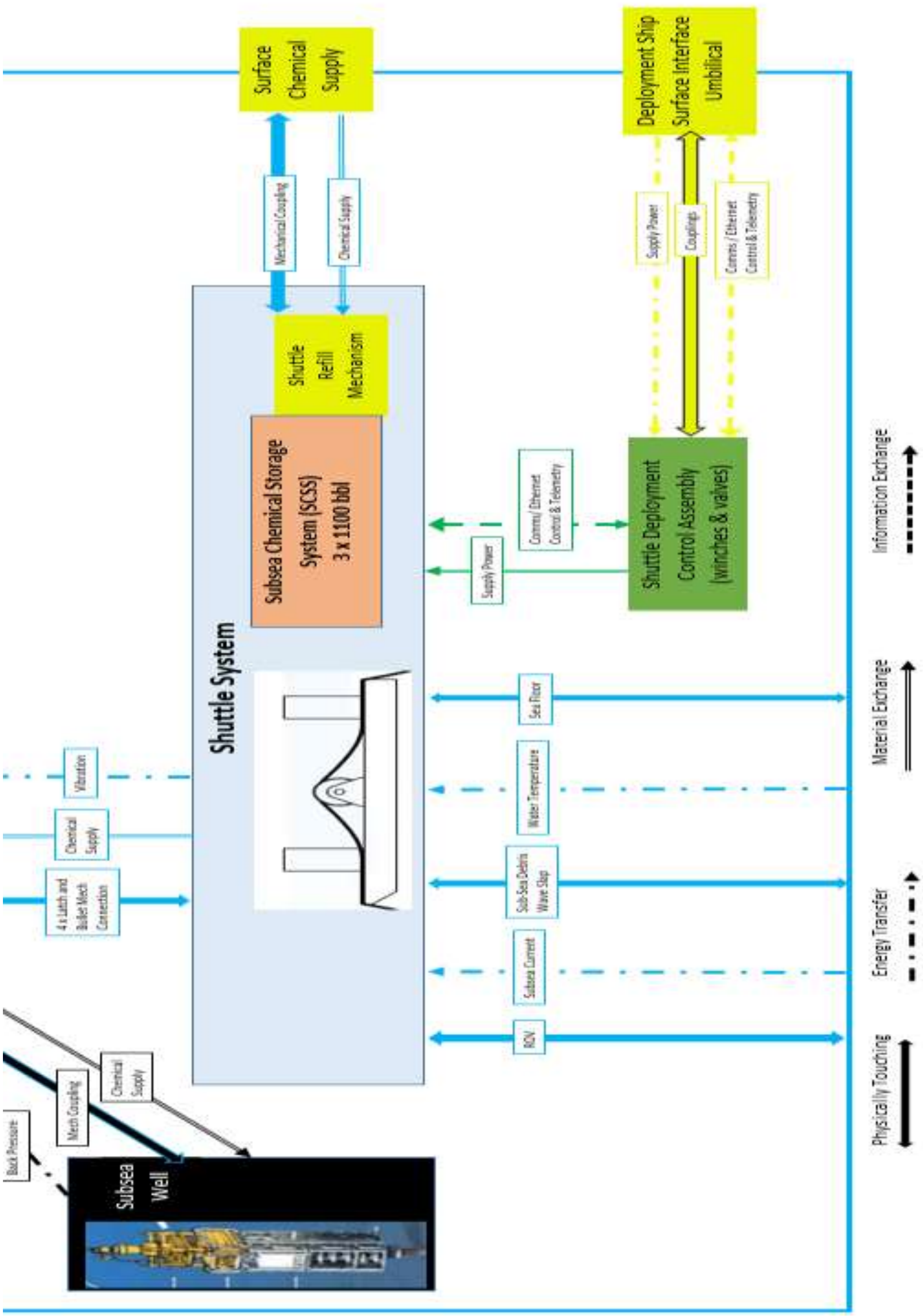


Figure 24: Shuttle, SCIU and SCSS interfaces

Figure 25 below depicts the overall systems parameters with details of,

- Control Factors detailed in Figure 26
- Signal Factors (Inputs) in Figure 27
- Noise Factors in Figure 28 and
- Response Factors (output) in Figure 29 and figure 30.

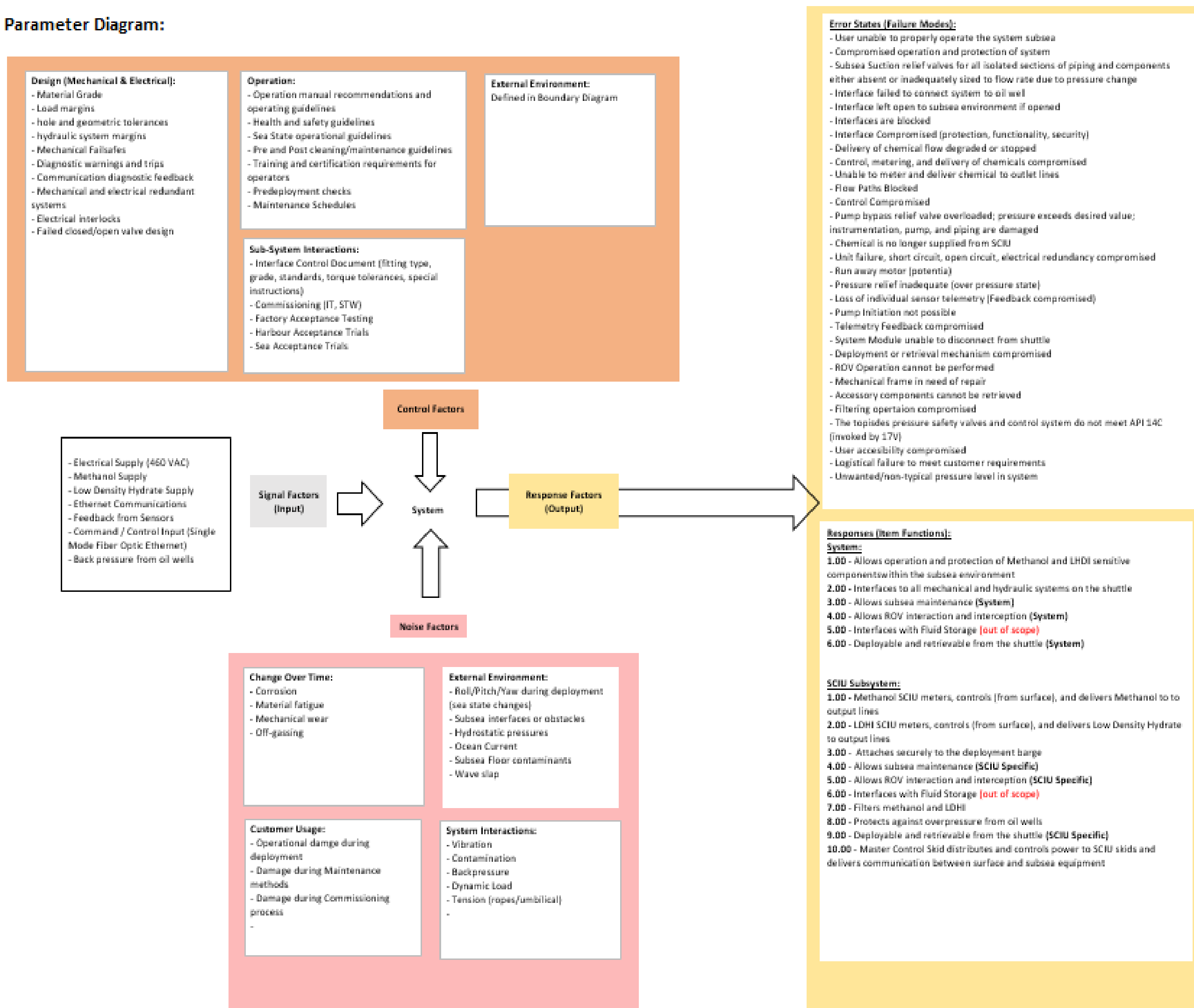


Figure 25: Overall systems parameter diagram

Design (Mechanical & Electrical):
- Material Grade
- Load margins
- hole and geometric tolerances
- hydraulic system margins
- Mechanical Failsafes
- Diagnostic warnings and trips
- Communication diagnostic feedback
- Mechanical and electrical redundant systems
- Electrical interlocks
- Failed closed/open valve design

Operation:
- Operation manual recommendations and operating guidelines
- Health and safety guidelines
- Sea State operational guidelines
- Pre and Post cleaning/maintenance guidelines
- Training and certification requirements for operators
- Predeployment checks
- Maintenance Schedules

Sub-System Interactions:
- Interface Control Document (fitting type, grade, standards, torque tolerances, special instructions)
- Commissioning (IT, STW)
- Factory Acceptance Testing
- Harbour Acceptance Trials
- Sea Acceptance Trials

External Environment:
Defined in Boundary Diagram

Figure 26: Control factors

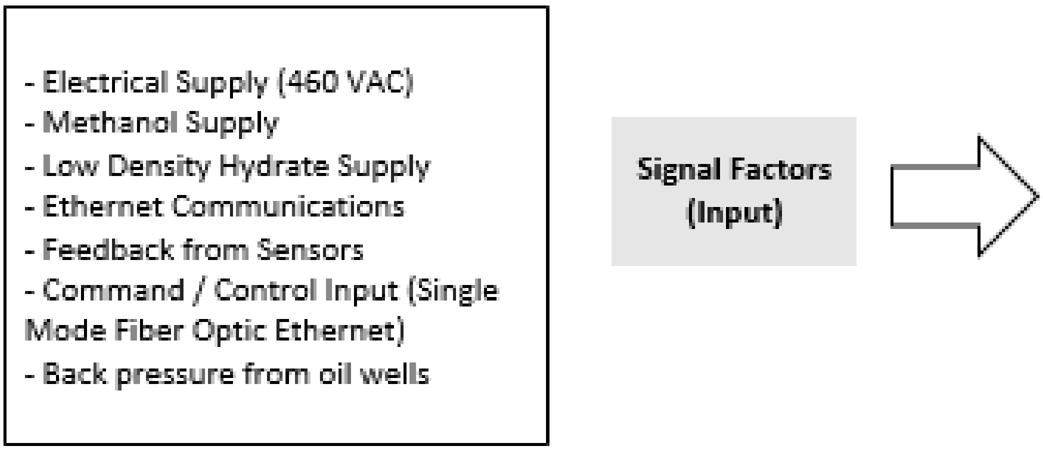


Figure 27: Signal factors

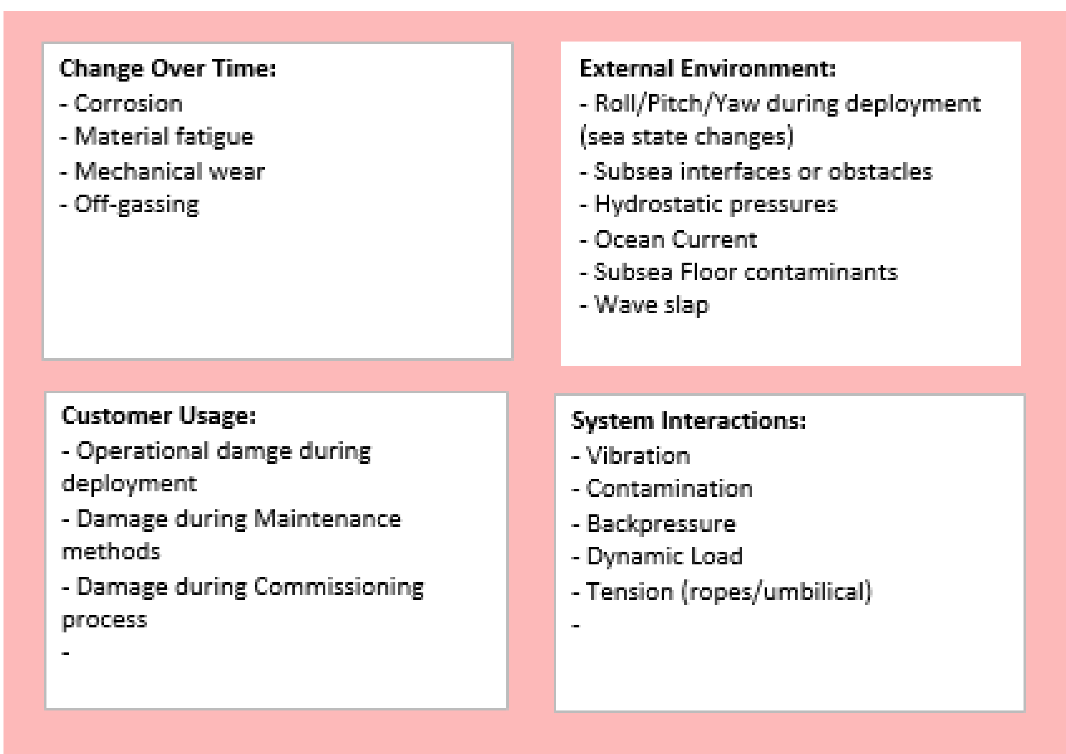


Figure 28: Noise factors

Error States (Failure Modes):

- User unable to properly operate the system subsea
- Compromised operation and protection of system
- Subsea Suction relief valves for all isolated sections of piping and components either absent or inadequately sized to flow rate due to pressure change
- Interface failed to connect system to oil well
- Interface left open to subsea environment if opened
- Interfaces are blocked
- Interface Compromised (protection, functionality, security)
- Delivery of chemical flow degraded or stopped
- Control, metering, and delivery of chemicals compromised
- Unable to meter and deliver chemical to outlet lines
- Flow Paths Blocked
- Control Compromised
- Pump bypass relief valve overloaded; pressure exceeds desired value; instrumentation, pump, and piping are damaged
- Chemical is no longer supplied from SCIU
- Unit failure, short circuit, open circuit, electrical redundancy compromised
- Run away motor (potential)
- Pressure relief inadequate (over pressure state)
- Loss of individual sensor telemetry (Feedback compromised)
- Pump Initiation not possible
- Telemetry Feedback compromised
- System Module unable to disconnect from shuttle
- Deployment or retrieval mechanism compromised
- ROV Operation cannot be performed
- Mechanical frame in need of repair
- Accessory components cannot be retrieved
- Filtering opertaion compromised
- The topisdes pressure safety valves and control system do not meet API 14C (invoked by 17V)
- User accesibility compromised
- Logistical failure to meet customer requirements
- Unwanted/non-typical pressure level in system

Figure 29: Response factors (failure models)

Responses (Item Functions):

System:

1.00 - Allows operation and protection of Methanol and LHDI sensitive componentswithin the subsea environment

2.00 - Interfaces to all mechanical and hydraulic systems on the shuttle

3.00 - Allows subsea maintenance **(System)**

4.00 - Allows ROV interaction and interception **(System)**

5.00 - Interfaces with Fluid Storage

6.00 - Deployable and retrievable from the shuttle **(System)**

SCIU Subsystem:

1.00 - Methanol SCIU meters, controls (from surface), and delivers Methanol to to output lines

2.00 - LDHI SCIU meters, controls (from surface), and delivers Low Density Hydrate to output lines

3.00 - Attaches securely to the deployment barge

4.00 - Allows subsea maintenance **(SCIU Specific)**

5.00 - Allows ROV interaction and interception **(SCIU Specific)**

6.00 - Interfaces with Fluid Storage

7.00 - Filters methanol and LDHI

8.00 - Protects against overpressure from oil wells

9.00 - Deployable and retrievable from the shuttle **(SCIU Specific)**

10.00 - Master Control Skid distributes and controls power to SCIU skids and delivers communication between surface and subsea equipment

Figure 30: Response factors

Figure 31 below summarizes the overall results as documented in Appendices reports

Results - 1133 FMECA Scores (Subsystem and System - Current Design - No Mitigation)					
	A-Unlikely	B-Remote	C - Occasional	D-Frequent	E - Very Frequent
1 - Minor	1	10	8	0	0
2 - Low	21	55	9	2	0
3 - Moderate	29	72	13	0	0
4 - High	24	62	5	0	0
5 - Very High	21	14	0	0	0

Figure 29: Overall System Validation via Design Failure Mode Effects and Criticality Analysis (DFMECA)

System Differentiators

The visuals in figure 32 below are provided to illustrate the differences between current practice for chemical supply to subsea wells (on the right a 1200 gallon, temporary) and the game-changing SMT concept (3000 barrel on the left. The first difference is found in the storage capacity.

SMT Large volume (3000 BBL) vs. multiple small (30 - 200 BBL) Chemical storage

Figure 30: Subsea Chemical Storage Tanks

A State Of The Art (SOTA) survey (Safe Marine Transfer, LLC, 2014) conducted by SMT determined that existing subsea chemical storage was typically achieved with small tanks, often one-time use plastic drums that are crushed by hydrostatic pressure as the chemical is removed from the tank and consumed. For larger volumes of chemicals multiple combinations of small tanks and control units are used and are remotely connected in time-consuming ROV seafloor operations. The 3,000 BBL SMT storage concept is far more efficient and cost effective for applications needing large volumes of chemicals. Additionally, the SMT installation (deployment and retrieval) procedure utilizes much smaller (and less expensive) vessels of opportunity (which minimizes delay and results in a lower mob-de-mob cost). Since the overall duration of marine operations is significantly reduced when contrasted to installing and connecting numerous (dozen ++) smaller storage units, the SMT process also results in a safer operation.

Low-cost vessels of opportunity vs. massive derrick barge

Figure 31: Offshore Support Vessels; anchor handler – left; heavy lift vessel – right (note relative size)

Safe and environmentally friendly marine support operations

- Order Of Magnitude (OOM) less costly marine operations (with system redundancies) using Anchor Handling Tugs (AHTs).
- Dual barrier chemical storage containment concept for safe transport, installation, and injection operation.

The SMT system uses two AHTs (Figure 24, left picture) for cost efficient support operations. When a large chemical tank is deployed by a large crane (right picture – see AHT in photo for comparison), it is costly and schedule sensitive, as such large cranes are not 'available' as vessels of opportunity.

The following (figure 34) illustrates the differences in approach between common offshore deliveries of chemistry to host platforms compared to the features of the SMT system.

Figure 32: SMT System Differences with Existing Practice

Stage II Tasks

8.0 Project Management Plan (Stage II)

Deliverable: Final Project Management Plan

Description: SUBCONTRACTOR (SMT) shall develop a Project Management Plan –STAGE II consisting of a work breakdown structure and supporting narrative that concisely addresses the overall project as set forth in the subcontract. SUBCONTRACTOR shall provide a concise summary of the objectives and approach for each Task and, where appropriate, for each subtask. SUBCONTRACTOR shall provide schedules and planned expenditures for each Task including any necessary charts and tables, and all major milestones and decision points. SUBCONTRACTOR shall identify key milestones that need to be met prior to the project proceeding to the next phase. This report is to be submitted within thirty (30) calendar days of STAGE II approval. The Project Manager and Working Project Group shall have twenty (20) calendar days from receipt of the Project Management Plan to review and provide comments to SUBCONTRACTOR. Within fifteen (15) calendar days after receipt of comments, SUBCONTRACTOR shall submit a final Project Management Plan to the Project Manager for review and approval.

Summary: A draft Project Management Plan (PMP) was delivered on 05/09/2015. Comments were received and final agreed PMP published on 07/18/2015.

9.0 System Engineering and Integration

Deliverable: No specific report for this task

Description: SUBCONTRACTOR shall coordinate all disciplines to produce a functional and qualified design for the subsea chemical storage and injection system. This includes all interfacing with Research Partnership to Secure Energy for America (RPSEA) and National Energy Technology Laboratory (NETL) entities, regulatory coordination, classification societies, and compliance with standards for both the shuttle and the process systems.

Summary: Work was performed by SMT on a regular ongoing basis. See Summaries of work in Attachment 2 as well as Figure 2 in the Introduction section.

10.0 Process Systems

Deliverable: Detailed process design from subcontractors reported in the STAGE 2 Final Report

Description (SOW): SUBCONTRACTOR (SMT) shall work with the Subsea Chemical Injection Unit (SCIU) and the Storage Systems (Bladder) OEMs to develop detailed designs and their qualification process. This includes the pumps, process sensors, instrumentation and all other ancillary components required for proper operation of the injection function, the power system, and the in-situ refill nozzle. OEMs for this work are expected to include OceanWorks International (SCIU) and yet to be named a Storage System (SS - Bladder) manufacturer and a chemicals / materials testing lab for the material chemical compatibility and testing activities supported with advice and consultation from Baker Hughes Inc. (BHI).

Summary: See section 12 for SCIU work, section 13 for SCSS work.

11.0 Reporting

11.1 Tech Transfer, Routine Reporting & Subject Matter Expert (SME) Contributions

Deliverable: Tech Transfer Support and Routine Reporting.

Description: This subtask includes STAGE II tech transfer activities, routine reporting support and SME contributions over the duration of STAGE II.

Summary: Tables in Attachment 3 summarize all Tech Transfer activities during the course of the Project.

11.2 Final Report

Deliverable: Final Report on Stage II work and Final Presentation

Description: The SUBCONTRACTOR (SMT) shall document a summary of all of the work performed in this STAGE II Project into a Draft Final Technical Report, and shall include recommendations and a plan for further development. The RPSEA Technical Coordinator assisted by the WPG will review and comment on the draft. The SUBCONTRACTOR shall then address comments and submit a Final Technical Report for acceptance. The Final Report will include a summary of risk assessment work in Stage II and will include a summary of key risks to be addressed in commercialization. The Final Report will further include a recommendation for additional improvements and testing if applicable. The SUBCONTRACTOR shall prepare a Project Final Presentation to present at a Technical Advisors Committee (TAC) or other event agreed to by RPSEA. The presentation materials shall be submitted 14 calendar days after the presentation but before the Project End of Performance Period.

Status: All Stage II work is substantially complete and documented herein.

12.0 Subsea Chemical Injection Unit (SCIU)

SMT subcontract OceanWorks to prepare the detailed SCIU and control system design sufficient for fabrication quote preparation. Their proven performance with the MWCC dispersant system and other related work brought significant value to the performance of this work.

12.1 Project requirement

Deliverable: A technical report documenting the detailed design and qualification provided to SMT

Description: SUBCONTRACTOR (SMT) shall use their qualified products and products qualified by others to develop the Subsea Chemical Injection Unit (SCIU), its power supply, its control system and the associated process instrumentation to deliver a qualified process design. Two scenarios are to be developed. One is for batch treatment of methanol and the second is for the continuous injection of LDHI and other chemicals (if approved). Design Specification Document for System and Major Subassemblies will be prepared and will include:

- Interface Control Document (ICD)
- Compliance Matrix
- Schematics
- Conceptual Drawings and Bill Of Materials (BOM)
- Design Failure Mode and Effects Analysis (DFMEA)
- Inspection Maintenance and Repair (IMR) outline
- CONOPS (Concept of Operations), Hazardous Operations Study (HAZOPS) and Hazard Identification (HAZID)
- Qualification Gaps & Design Limitations to achieve minimum TRL4
- Cost Estimate for the design and fabrication
- Design of the Refill Nozzle System
- Design Document
- Design Reviews

12.1 SCIU - Results

Status: Completed. The detailed design is included in the subcontractor's reports.

Summary: The subcontractor work was completed and summarized into presentations used for the Stage 2 DFMECA reviews.

See Appendix 2 for design and engineering details.

Overview

The overall system consists of a subsea chemical storage system (the SCSS), a subsea chemical injection unit (the SCIU), and a flying lead to deliver chemical to the injection points on the subsea well. (See Figure 35 for SCIU placement on Shuttle and Figure 36 for SCIU detail).

Both the SCSS and SCIU are located within an assembly known as a Shuttle. The Shuttle is a barge that can be deployed on-site by being towed on surface and then submerged to the seafloor and subsequently recovered and re-deployed.

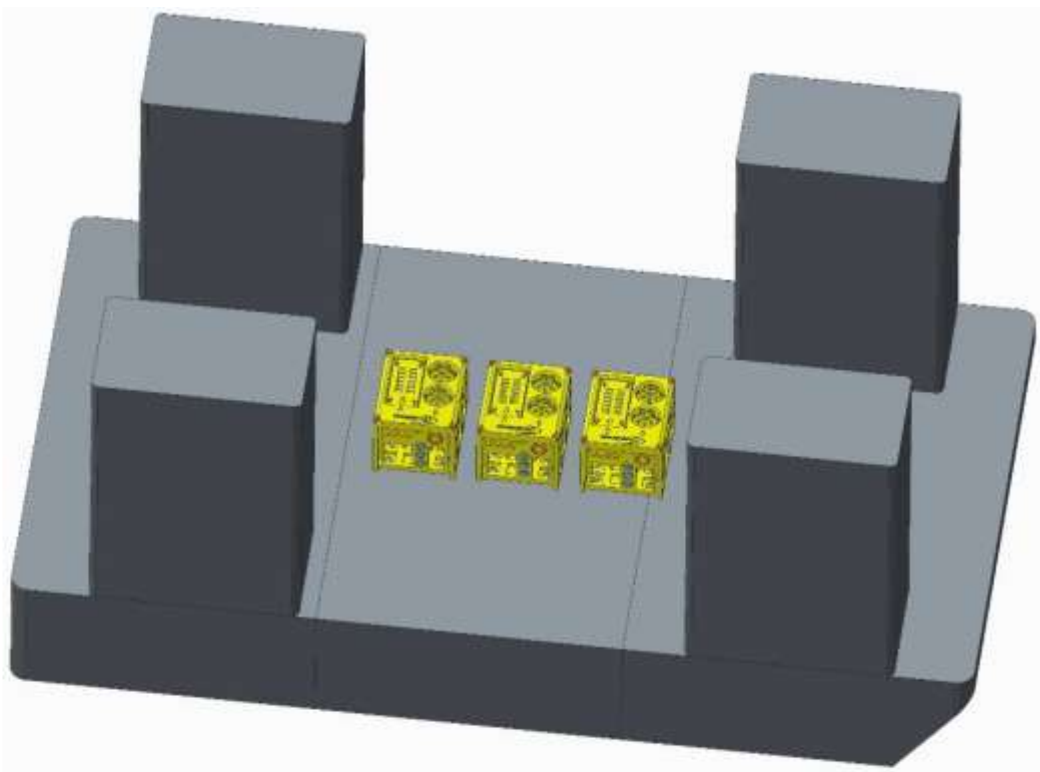


Figure 33: Shuttle with SCIU's Mounted on Shuttle Deck

The Subsea Chemical Storage System (SCSS) is a pressure compensated chemical reservoir is a rigid container that has an interior pressure equal to the local (subsea) ambient pressure. The chemical is stored inside a bladder that is within the SCSS. The SCSS provides the second barrier in the dual barrier chemical containment storage system

There are two concepts of this system: (1) a large version that pumps methanol in discrete events during well shutdown and startup, and (2) a smaller system that pumps lower flow rates of chemical continuously.

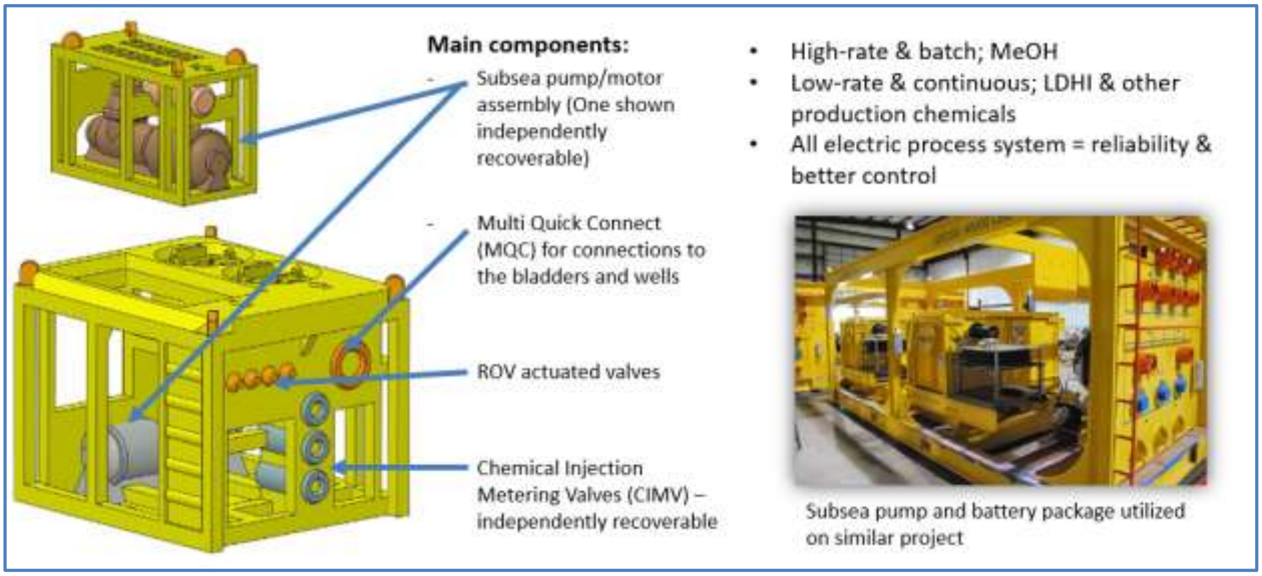


Figure 34: Subsea Chemical Injection Unit (SCIU)

Philosophical Guidelines

Certain principles are applied as guidelines to support a successful product. These are described below.

Primary

- Economics: the system will be economically attractive compared to the alternative of a standard subsea chemical umbilical.
- Reliability: the system will use Common Off The Shelf (COTS) components and hardware with as high a TRL as possible.
- Proof of concept: there will be demonstrated evidence that this design is proven to work. Where not proven, there will be a detailed description of the existing state of proof and the detailed requirements to obtain such a proof.
- Modularity: the system will be configured so that components can easily be scaled up in quantity, and so that a host system can easily be adapted to support such an increase.
- Design transparency: sufficient design algorithms such as calculations will be provided so that the baseline design can be scaled in size and adjusted in performance to match a specific application. The form of the calculations will have sufficient transparency (e.g., they will show the actual formulae used), that their results can be reproduced.

Secondary

Common parts will be used throughout the system wherever practical. For example: piping diameter, valve types, flange sizes. If different sizes are needed, the number of categories will be minimized.

Generic components and materials will be used where practical.

When faced with a make versus buy decision, the preference will be to buy.

Problematic material combinations will be minimized or eliminated. For example: galvanic corrosion and the use of duplex stainless exposed to CP should be avoided.

Economic components, manufacturing methods, and simplified designs are preferred.

Overall Layout

There is a Shuttle barge that contains bays that can be accessed from above and partially from one or more sides. The bays are identical. The dimensions of the bays, attachment points, and side access to the subsea hardware is described in the ICD, document number 1133-000-E00040.

The SCSS chemical bladders are located inside and protected by the Shuttle barge. Attachment points secure the bladder assemblies to the shuttle structure. The attachment points locate the hardware in 6 degrees of freedom (3 translation and 3 rotation), and transfer transportation and deployment loads.

The upper surface (roof) of the SCSS structure is the mount interface for the SCIU pump station structure.

When it is subsea, the SCIU can be removed from the SCSS by an ROV.

This design applies to two systems: one that pumps methanol, and another that pumps LDHI chemical. The methanol and LDHI systems are located on separate shuttles in this design.

The system piping is shared between the SCSS and SCIU, so that the SCIU can be removed from the SCSS while subsea with a minimum number of disconnections.

All hydraulic connections, electrical connections, components that need to be inspected or removed and replaced by ROV, will be located in as central a location as practical and will be ROV accessible.

Components that need to be accessible for inspection, removal, or replacement while subsea will be identified, located to maximize ROV accessibility, attached to the structure and connected to it electrically and hydraulically, to maximize ease of inspection, removal, and replacement. This will typically mean that they will be near the top and outsides of the structure. Appurtenances will be provided, and design considerations investigated, to facilitate subsea lifting. This likely will entail hot stabs, wet mate connectors, stab plates, land-out bullets, structural latches, ROV grab handles, pad-eyes, verification of the lifting load path, and verification that the CG location is underneath the centre of the lifting padeye pattern.

Subsea Chemical Injection Unit – SCIU.

The SCIU is simply stated a pump(s), controls, instrumentation, sensing and metering equipment packaged together as a unit that takes suction from the SCSS (Chemical Bladders) and then pumps (or depending upon pressure differentials) allows chemical to flow to the point of use. Specifically, a design has been qualified for two (2) major scenarios; one for methanol injection during which large volumes of methanol are quickly pumped during well transition conditions (start-up, shut-down). The other scenario is for Low Dosage Hydrate Inhibitor (LDHI) in which chemical is continuously injected (in small volumes). Additionally, the SCIU design has the capability to inject other chemicals such as corrosion, asphaltene and scale inhibitors that may be used at lower rates. The injection system might also be configured to inject large volumes of dispersant if there is a need.

Pipes and related equipment such as flanges, valves, and connectors are required to be rated to 10,000 psi. The piping systems are designed and specified in accordance with API RP-1111 *Recommended Practice for Design, Construction, Operation, and Maintenance of Offshore Hydrocarbon Pipelines (Limit State Design)*. According to API RP-1111 section 2.1.7 (c), injection lines are covered by this code. Design pressure, burst pressure, allowable incidental overpressure, and test pressure are defined by this code. In compliance with this code, lower pressure rated portions of the overall unit are protected by high-pressure shutdown or pressure relief devices. The valves can be actuated either by an ROV (or AUV) or with electric actuators.

The SCIU is mounted to the shuttle such that it can be removed entirely and replaced subsea without having to move the Shuttle. Critical equipment sparing was specified to help ensure overall reliability. If the existing Christmas Tree subsea umbilical can supply the required power, then this is the preferred option because of minimal added cost. The small power demands, a few kilowatts total for all continuous chemical injection, will likely mean that LDHI and other continuous low-dosage chemical injection can be powered using power which is available in-situ. The much higher power demand for methanol injection, several hundred kilowatts to supply a 3 bbl / minute flowrate may make the use of available installed power a challenge. Depending on the installation, it is likely that additional power will need to be supplied to the SCIU, using one of the options below.

Subsea Power Umbilical from fixed existing surface assets.

A new subsea umbilical can be deployed, which provides one or more of the following:

- Electrical Power
- Communications
- Low Pressure Chemical Resupply

This umbilical, while expensive, would be less expensive than a conventional umbilical which needs to supply all of the above and several chemical types.

Subsea Power Umbilical from a new surface buoy near the drill center.

A power-producing buoy, for example a diesel generator, can be located at the surface above the drill center, providing continuous electrical power over a shorter and thus less expensive umbilical.

Subsea battery storage.

For Methanol the required power is large but for a short amount of time. Subsea batteries (Figure 27) can be stored near the SCIU and trickle charged from a small umbilical. Subsea battery storage is not required for LDHI injection due to the continuous nature of the power demand.

Leveraging existing Common Off-The-Shelf Technologies. (COTS)

At the conclusion of the SCIU design program it was determined that by leveraging existing solutions to similar applications (see Figures 37 and 38) all of the necessary components are commercially available and qualified for design service (Figure 29) with one exception. The singular exception is the methanol pump. The limiting factors are the 10,000 fsw and the low viscosity of methanol. A surface pump that has been proven with hundreds of thousands of hours of high reliability service with methanol was selected for adaptation to subsea use. Working closely with the manufacturer a Cost, Time and Resources (CTR) sheet has been constructed to guide marinization and qualification for this project. Under this CTR, considerable design and engineering work has been accomplished, including design of a pressure compensating enclosure and pairing with an equally suitable electric motor.

Figure 35: Subsea pump and battery package utilized on similar project

Figure 36: Subsea manifold – distribution system utilized on similar project

A six-well configuration with individual jumpers to each well was selected for development as it is the most complex arrangement (Figure 39). Figure 40 depicts the LDHI configuration. A similar configuration will be utilized for other low dosage chemicals such as corrosion inhibitors, biocides, asphaltene inhibitors, demulsifiers, scale inhibitors, etc. Some installations may only require a single large chemical jumper to a subsea facilities existing chemical distribution system while others would have several pumps and umbilicals pumping different chemicals at different flow rates simultaneously.

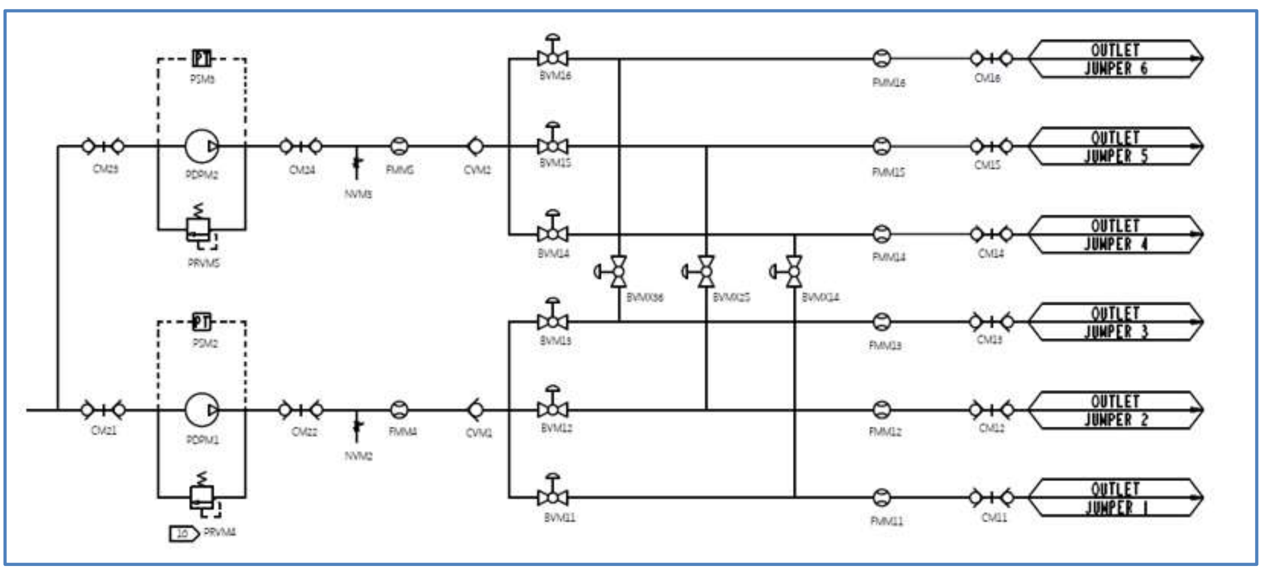


Figure 37: Six (6) well methanol pump and outlet end configuration

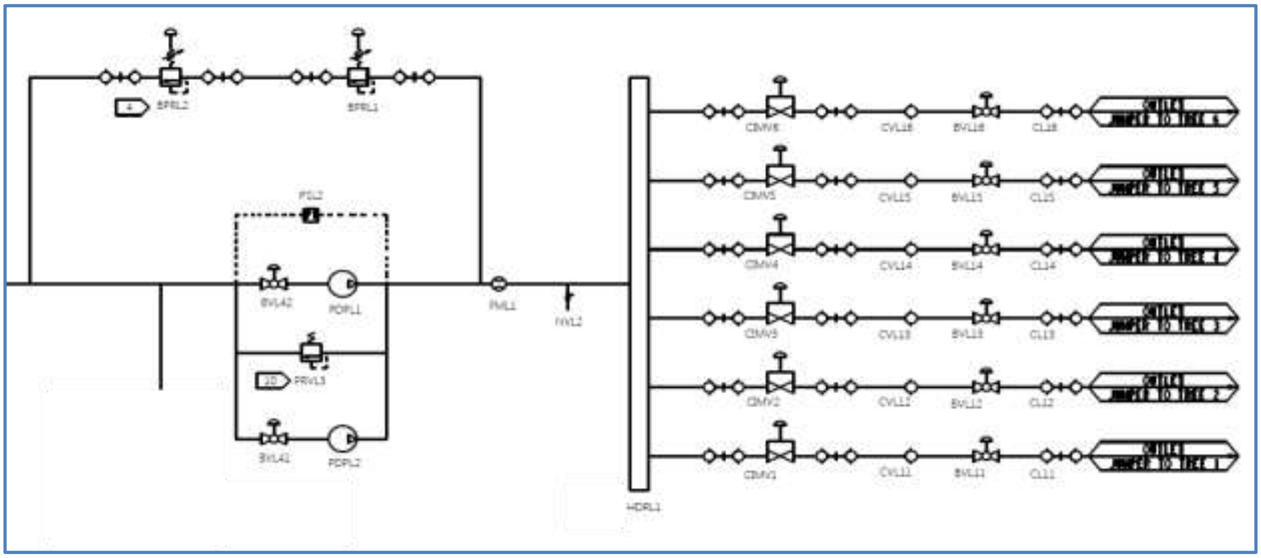


Figure 38: Output end of the LDHI design

In summary, via a detailed sweep across numerous manufacturers it was determined that existing, field proven kit can be integrated together to produce a fully qualified system to meet project design conditions – with the exception of the high pressure methanol pump, for which a detailed CTR has been developed and the initial stages already completed to close that single gap.

13.0 Subsea Chemical Storage System (SCSS)

Detailed design information and documentation can be found in Appendix 3. Summarized below are the major findings.

13.1 Project requirement

Deliverable: A Design Development Report for the Chemical Storage System

Description: SUBCONTRACTOR will select a qualified bladder OEM to prepare the design and qualification of the chemical and seawater storage bladder systems to be fitted within the shuttle's hold. The detailed design effort will include:

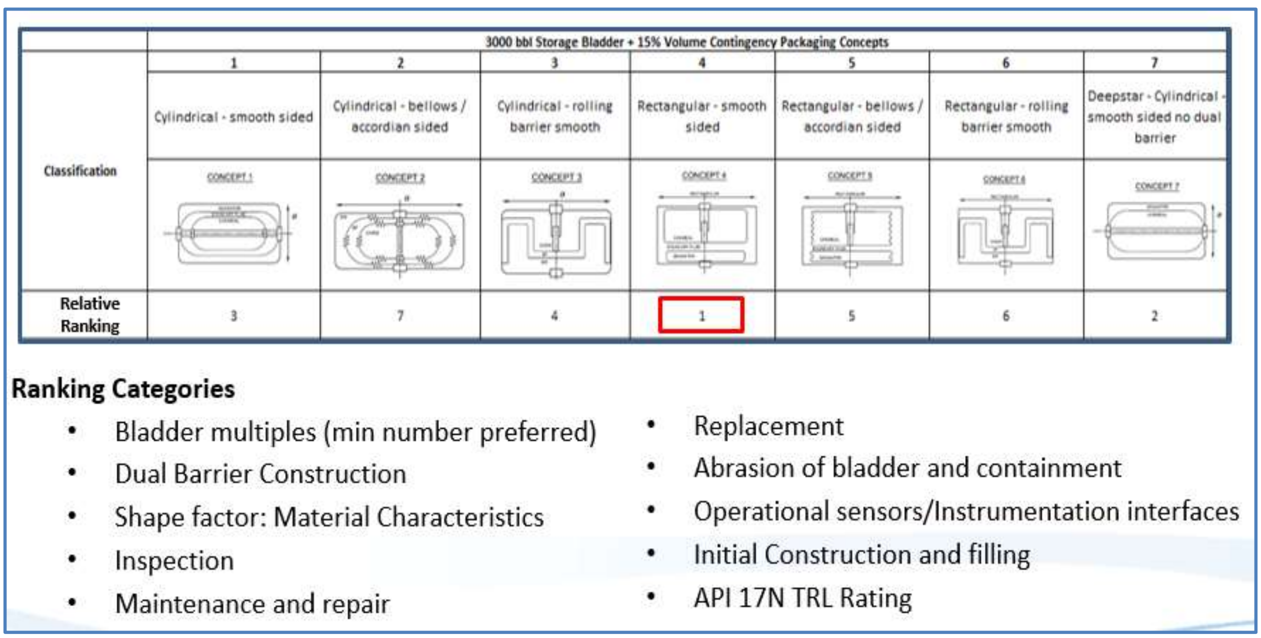
- Bladder material qualification and selection will be performed to identify materials with different production chemicals. The project may be increased to test materials for 3 additional chemicals (for a total of 6) which will be reviewed with the WPG before start of lab testing.
- Design of the bladders. The bladder OEM will provide the design for the bladder that will be supported within the walls of the shuttle hold.
- Fabrication specifics for the bladders. These will be specific to the materials used to fabricate the bladder and should be existing fabrication processes.

- FAT and routine bladder inspection procedures for the bladder.
- Analysis of the bladder and/or scale testing to confirm bladder behavior during operation.

The flexible bladder was identified as a critical component within the system due to its compatibility and chemical resistance with the different production chemicals. Bladder evaluation consists of three steps:

- A literature review of basic chemical – material compatibility. This review suggests that a fluoropolymer or a PVC coated fabric is a viable alternative.
- A basic chemical screening process in which nine candidate materials were exposed and sampled over a 28-day period in the three different fluids was conducted. For these screening tests, the fluids, seawater, methanol and LDHI, were provided by Baker Hughes.
- An accelerated aging test for material/chemical combinations was performed during the Stage 2 program of work.

The bladder material qualification process was developed and demonstrated during Stage 1 work (Stress Engineering Services, 2015). The bladder conceptual design was also developed and analyzed during Stage I work (Stress Engineering Services, 2015-03-11). See a summary of concepts analyzed in Figure 41 below.



	3000 bbl Storage Bladder + 15% Volume Contingency Packaging Concepts						
	1	2	3	4	5	6	7
Classification	Cylindrical - smooth sided	Cylindrical - bellows / accordian sided	Cylindrical - rolling barrier smooth	Rectangular - smooth sided	Rectangular - bellows / accordian sided	Rectangular - rolling barrier smooth	Deepstar - Cylindrical - smooth sided no dual barrier
	CONCEPT 1	CONCEPT 2	CONCEPT 3	CONCEPT 4	CONCEPT 5	CONCEPT 6	CONCEPT 7
Relative Ranking	3	7	4	1	5	6	2

Ranking Categories

- Bladder multiples (min number preferred)
- Dual Barrier Construction
- Shape factor: Material Characteristics
- Inspection
- Maintenance and repair
- Replacement
- Abrasion of bladder and containment
- Operational sensors/Instrumentation interfaces
- Initial Construction and filling
- API 17N TRL Rating

Figure 39: Bladder concept analysis

During Stage I there was also a 're-visit' regarding the size of the bladders. The question presented was is it preferable to have a single large bladder or multiple smaller ones with the same (3000 barrel) aggregate volume; a Single Large vs. Multiple Small? For reasons summarized in Figure 42, there was overwhelming guidance to continue the course with the large bladder concept. The exercise did bring good value. As a result, SMT did decide to design forward with three (3) large bladders versus a single very large design[1]. It should also be noted that the SMT design does 'scale down' and much smaller configurations are available for low rate chemical storage.

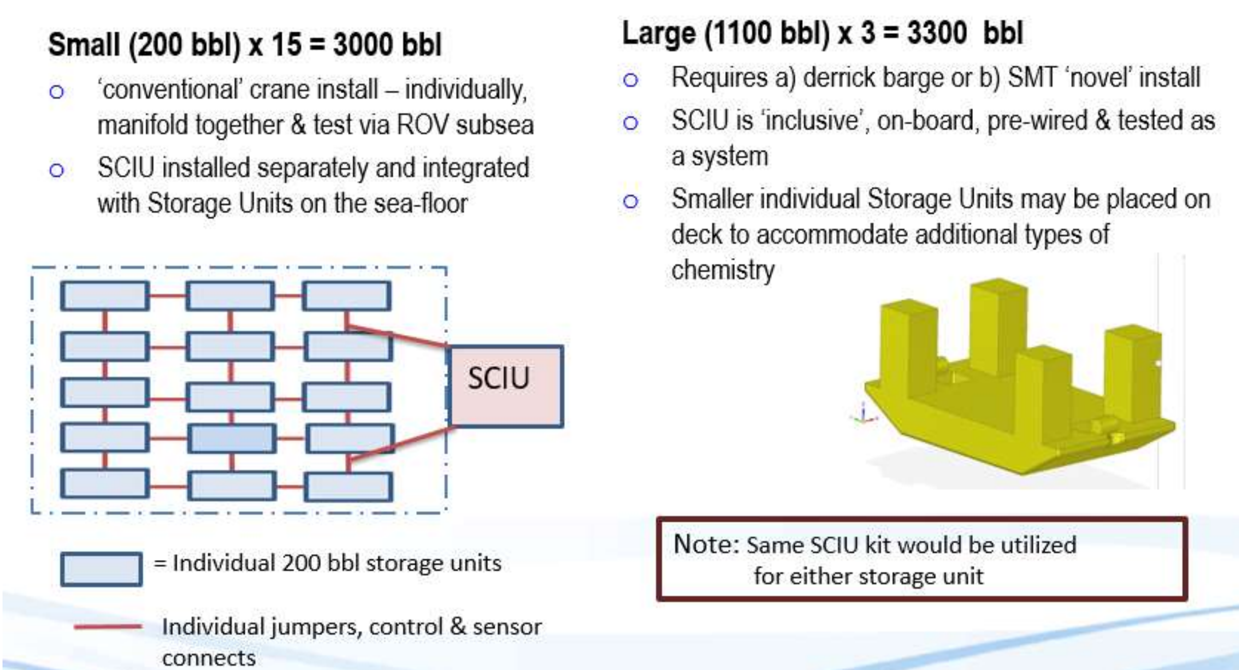


Figure 40: Comparison of multiple small storage units versus SMT system

13.2 Design

The Shuttle is designed to carry an array of chemical cargo. Three 1,000-barrel net (1,100-barrel gross) separate cargo cells allow the delivery of multiple chemicals from the same Shuttle. The chemicals are contained within a flexible Product Bladder that is supported by the walls of the cargo cells, or Holds. The maximum allowable Hold pressure is a 10 psi differential and the working differential pressures are to be held below 5 psi. The average cargo density range is from 0.79 to 1.025 Specific Gravity (SG.) Examples of chemicals that meet this are as follows:

- 100% Methanol (MeOH) with 0.79 SG
- 100% Low Dosage Hydrate Inhibitor (LDHI) with 0.98 SG
- 67% Monoethylene Glycol (MEG) with 33% MeOH with average 1.0 SG; where the different chemicals are held within separate tanks.

The Product Bladders of course 'collapse' or deflate as the chemical is pumped out. Depending upon the SG of the chemical, the Product Bladder can either collapse 'up' or 'down' as shown in Figure 43 below.

[1] As a point of reference, several bladder manufacturers routinely build and deliver 5000 barrel bladders.

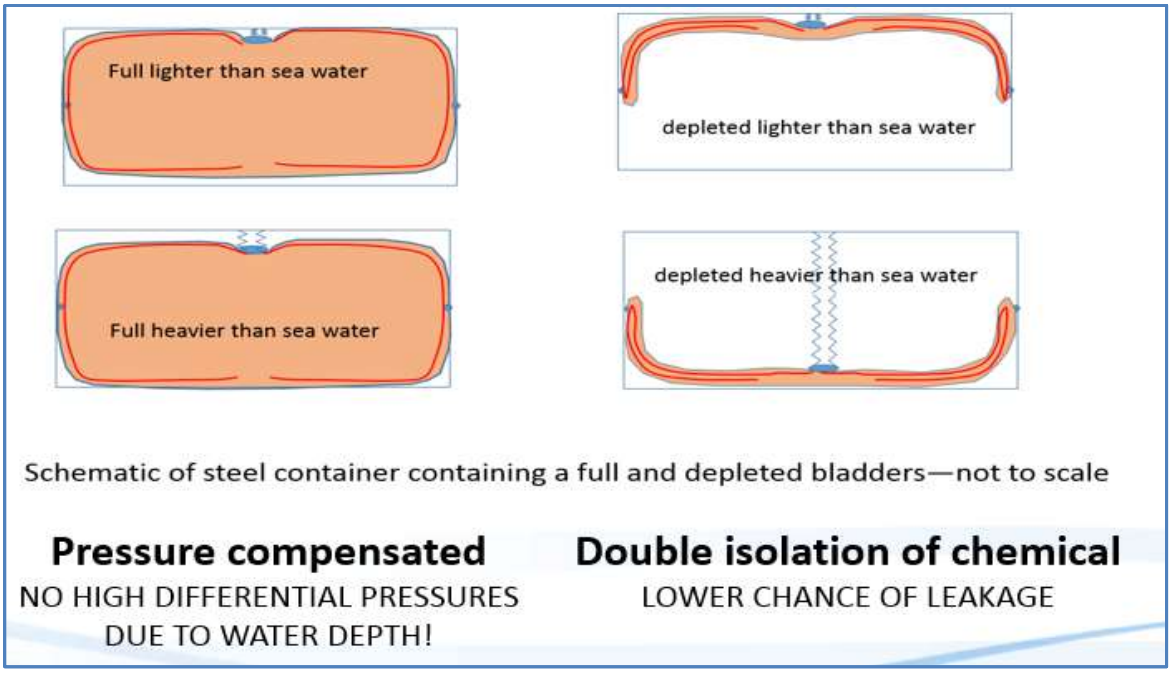


Figure 41: Product Bladders Shown in Shuttle Hold

Engineered flexible materials have been utilized in numerous applications, from consumer products, aerospace and defense. Below it can be seen on an amphibious assault boat capable of traversing very challenging beach landing environments (Figure 44). For decades, engineered fabrics have also been utilized for inexpensive fluid storage in remote and harsh environments, though mainly in land-based applications. The flexible Product Bladders specified for the subject design have been engineered to be fit for purpose and for specific chemical use with both the material manufacturers and Product Bladder fabricators, and then validated with third party testing (Figure 45) is an example of bladder testing for previous applications).

Figure 42: Engineered fabric being utilized in critical duty military service

Figure 43: Large bladders undergoing testing

To meet the wide range of production chemicals in use today, a single existing fabric type does not appear to exist. By matching different types of engineered fabrics with each chemical, suitable combinations were identified. Another variable in the solution was the actual bladder design configuration. SMT worked with two (2) teams as shown in Figure 46 to meet industry needs.

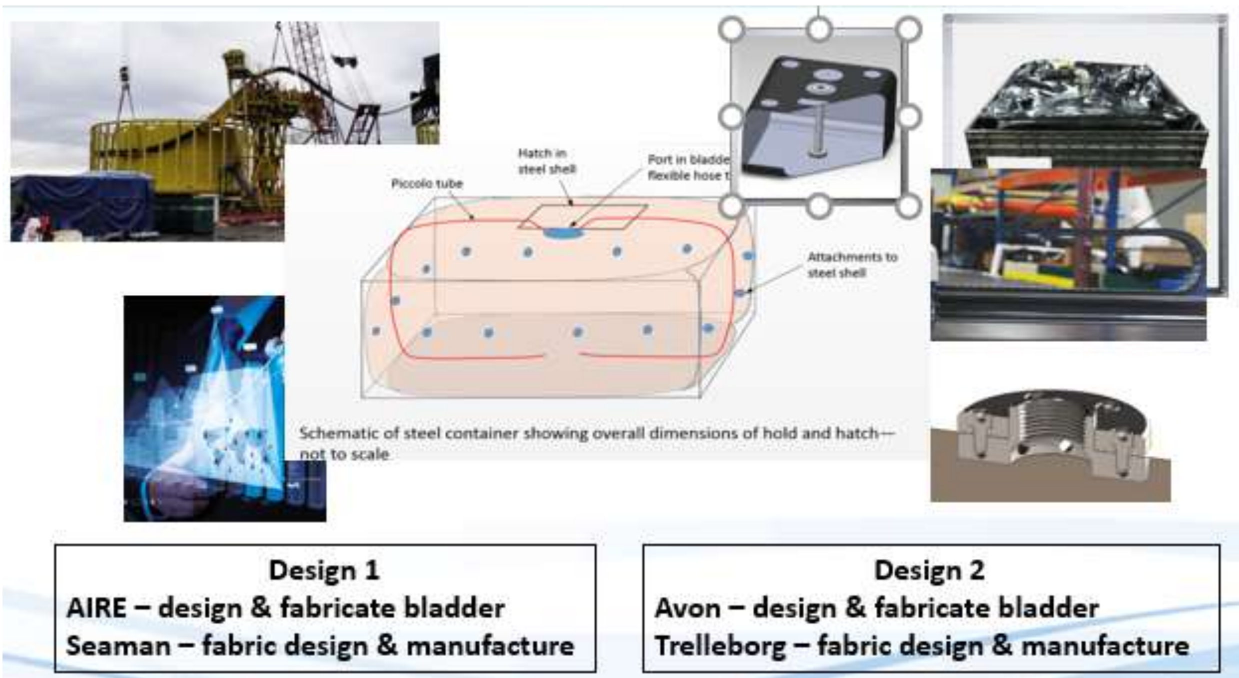


Figure 44: Two competing designs - plastic type material and an elastomer

Shown below in figure 47 are the two (2) actual scale model bladders.

Figure 45: Scale model bladder, left plastic and right elastomer versions

General concept, pressure compensation with flexible bladders subsea.

Double containment for the Shuttle is achieved through the use of a double bottom and wing tanks surrounding the cargo spaces, i.e., the Product Bladders. To prevent leakage to the environment should the bladder burst, a patent pending containment system with an Expansion Bladder will be used as described below.

At the beginning of deployment (Figure 48), the Expansion Bladder is void of air and liquid and the valve leading to it is closed. The sea-chest valve is open and the isolation valve is closed. The check valve allows seawater to enter the Bladder Cell to compensate for compression of the chemical and seawater in the compartment as the ambient water pressure increases during descent.

During the discharge (production) (Figure 49) of Chemical the check valve also allows seawater to enter the Bladder Cell to displace the discharged Chemical. When the Shuttle is ready for recovery the sea-chest valve is closed and the valve to the Compensation Bladder is opened. As the liquid inside and surrounding the Chemical Bladder expands it fills the Compensation Bladder. For in-situ refilling (Figure 50) the isolation valve is bypassed to allow seawater to flow out of the Bladder Cell while the Chemical Bladder is filled. During all phases a contamination sensor monitors the water surrounding the Chemical Bladder for any possible leaks.

During discharge, the annular space around the Product Bladder will be progressively filled with sea water. The hull provides a containment barrier (double on bottom and sides) in the event of a bladder leak. Seawater is now allowed to flow into the annular space as the liquid inside the Bladder Cell compresses or the cargo is dispensed. However, an inline check valve prevents the seawater from leaving the Bladder Cell in case there is any contamination, providing additional barrier to chemical leakage.

During recovery (Figure 51) the sea-chest valve is closed and a valve leading to an Expansion Bladder is opened. The Expansion Bladder is located outside the Bladder Cell in the wing space of the barge. The Expansion Bladder is void until the valve leading to it is opened. As the liquid in the Bladder Cell expands during recovery it flows into the Expansion Bladder.

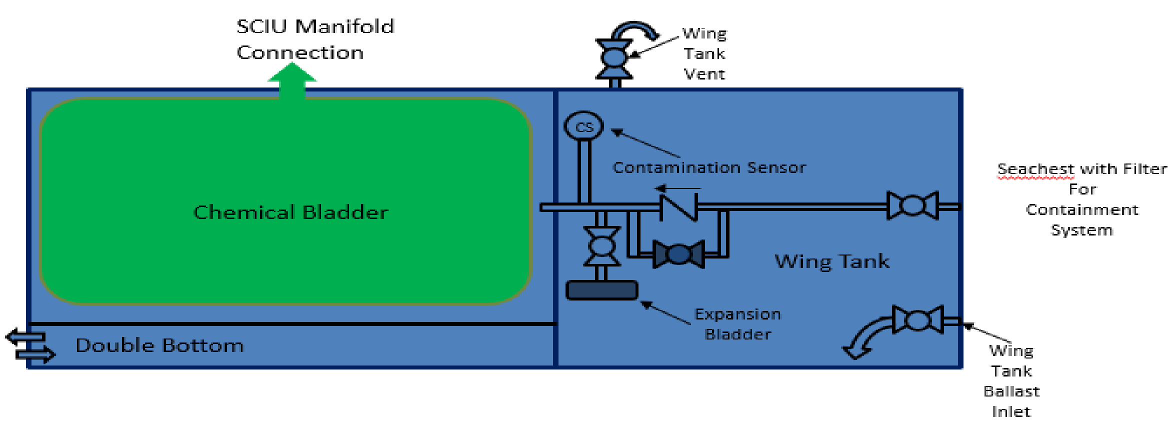


Figure 46: Deployment configuration

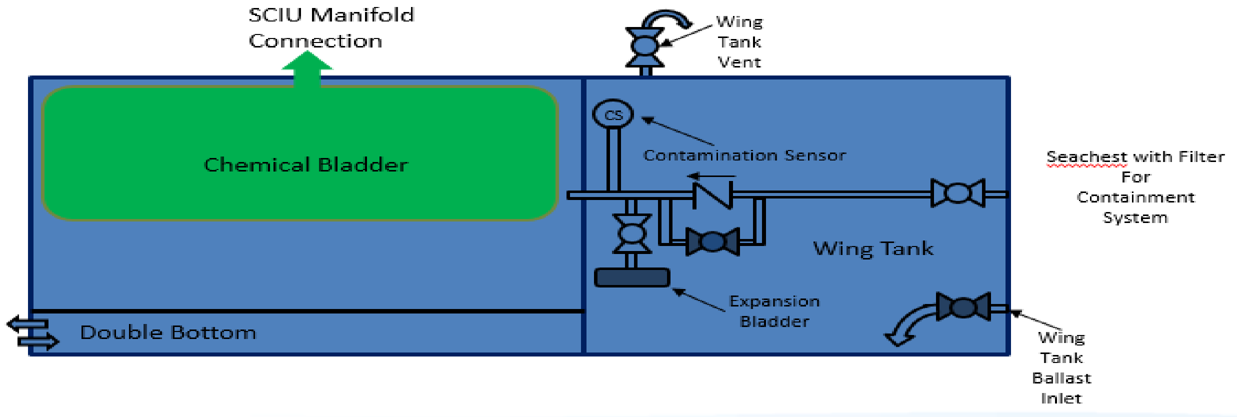


Figure 47: Seafloor installation, during discharge (production of chemical)

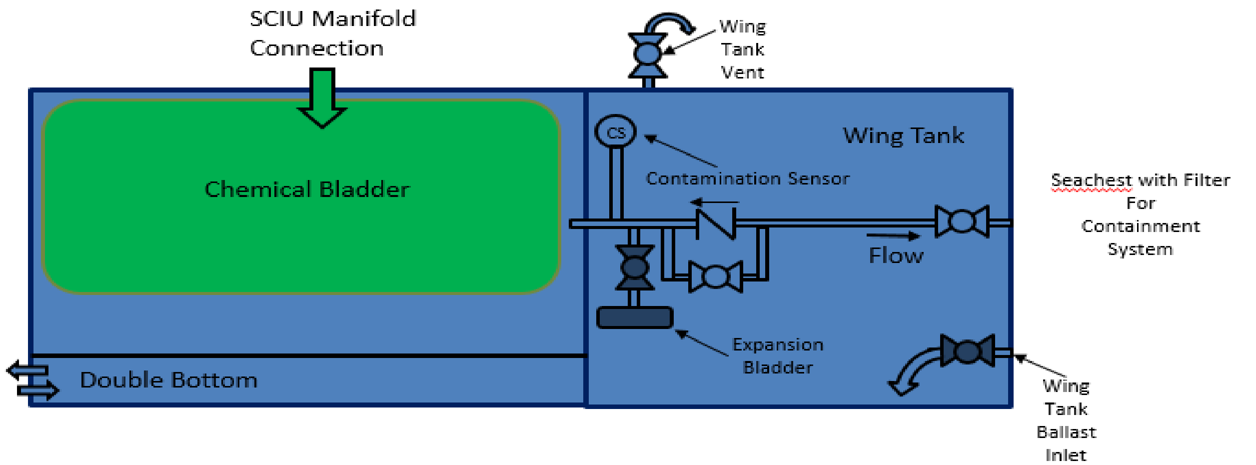


Figure 48: In-situ refill configuration

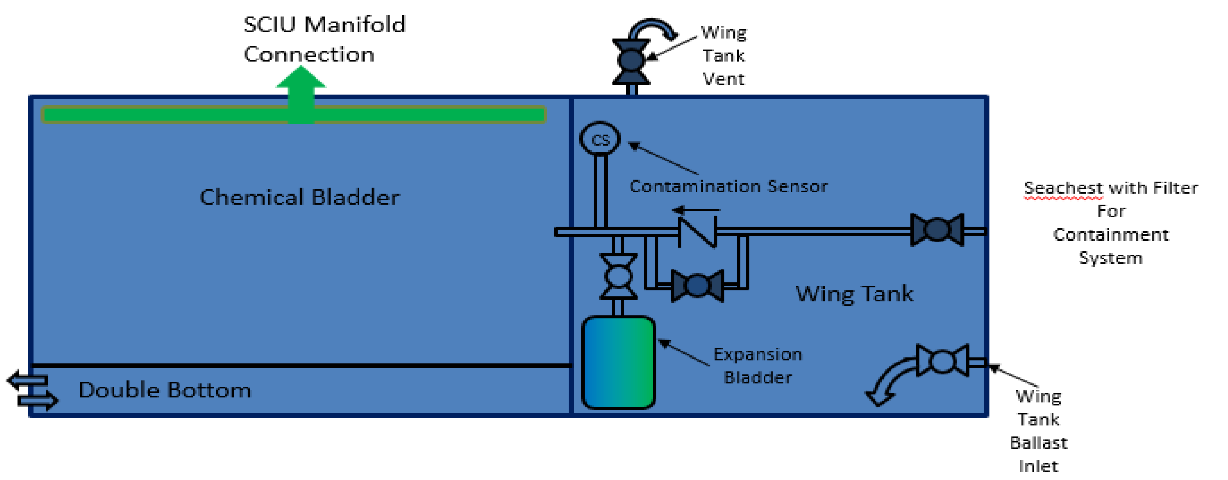


Figure 49: Recovery to surface configuration

Measurement / sensing

A study was conducted to overview possible technologies to sense two variables for operation of the subsea chemical storage system (SCSS). These two variables are:

1. A contamination (leak detection) sensor for use within the seawater discharge port to determine the integrity of the subsea storage bladder.
2. A tank volume sensor for a direct measurement of the chemical storage within the bladder

Possible approaches using these technologies are also briefly characterized. The relevant key requirements are:

- Maximum operating depth of 10,000 feet of seawater
- Long-term operation without intervention (e.g., >=6 months)
- Commercially-off-the-shelf (COTS) with little or no modification

Information was sought to show examples that are thought to be of reasonable size, weight, and power for practical implementations within the overall system and are thought to have reasonable electrical and mechanical interfaces to support remote subsea operation.

Contamination Sensing

The chemicals stored in SCSS are stored subsea within three fabric coated bladders, each with a volume of approximately 1,100 bbl. In addition to other systems, processes, etc. in place, it is being considered to have sensor system(s) in place to monitor for chemical leakage from the chemical bladders (figure 52). This section explores this topic.

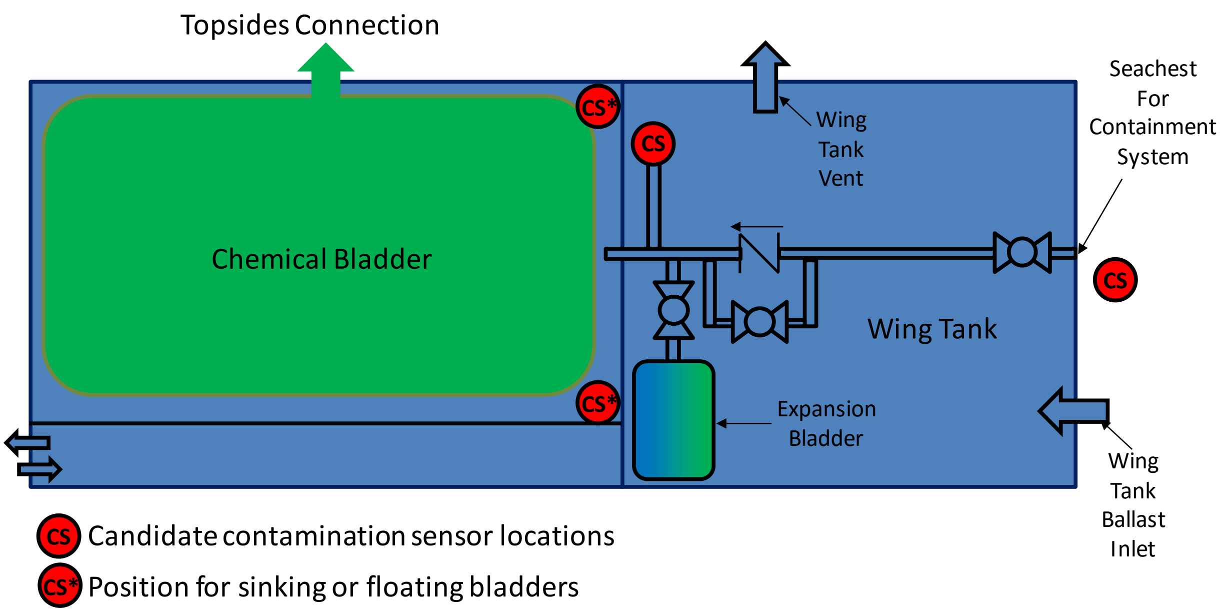


Figure 50: Candidate contamination sensor mounting locations

Given the wide range of chemicals being stored, see Figure 53, coupled with the long-term 10,000 fsw operational requirements, it was clear that chemical-specific sensors for this application are not practical. This observation is also supported by the requirement to use only COTS products with no or little modification.

Inhibitor	SGc	dSG
Methanol	0.79	0.235
Paraffin Inhibitor	0.84	0.185
Anti- Agglomerates (AA)	0.85	0.175
Asphaltene Inhibitor	0.85	0.175
Demulsifier	0.87	0.155
DRA	0.87	0.155
Corrosion Inhibitor	0.89	0.135
Asph. + Paraffin Cocktail	0.92	0.105
KHI	0.96	0.065
Scale + Corrosion	0.98	0.045
Seawater	1.025	0
Scale Inhibitor	1.1	0.075
MEG	1.2	0.175

Figure 51: Examples of production chemicals

Given long-term subsea chemical-specific sensors are not available, the following other approaches were conceived (not-ranked) with preliminary consideration(s) and assumptions below each:

1. Spike chemicals with dye and use a dye sensitive sensor to detect leaks
   a. Assume the spiked chemical permeating into seawater can be detected (and perhaps measured) with time and increased permeation may be an indication of impending bladder failure
   b. Bladder failure is expected to be sensed as a step change in the chemical concentration detected in the discharge seawater (especially during bladder chemical refill operations)
   c. Single sensor system for large range of chemicals
   d. Overcomes impractical direct subsea sensing of large range of chemical species
   e. Dyes are commonly used for leak inspection subsea in Oil & Gas (O&G) and other sectors
   f. Examples of candidate sensor mounting locations are shown in Figure 50: Candidate contamination sensor mounting locations, note sensor modifications may be required in some locations.

2. Maintain slight negative pressure on chemical storage bladder and monitor for seawater ingress
   a. Sea water ingress sensors are quite common; however, most are designed to detect seawater near full concentration and concentration is very small among a host of other non-desirable factors and issues.

3. Do pressure-hold tests on the bladder periodically (e.g., positive pressure on bladder and hold for x-time with < y pressure decay being acceptable)
   a. Suspect false-positives will be high due to huge-compliance/creep of the bladder while under pressure (e.g., bladder membrane creep to relieve internal pressure). Also, to do this you would have to open to sea to pressure test, hence filters would have to be used while pumping out to sea.

Spiking chemical with dyes was the preferred approach of the conceived options. Examples of dyes and sensors systems were investigated to show examples that are consistent with the COTS with little or no modification requirement.

Direct Subsea Chemical Storage Volume Measurement

The chemicals stored in SCSS are stored subsea within three fabric coated bladders, each with a volume of approximately 1,100 bbl. In addition to indirectly monitoring the volume of chemical in the bladder by flow and time measurements with the flow management system, it is desired to have sensor system(s) in place to more directly measure the volume of chemical in a given bladder. This section explores this topic.

Given the flexible and sealed/closed nature of the SCSS bladders, direct measurement of chemicals presents some interesting challenges in this subsea application. A collection of viable approaches was conceived and associated key technologies sought to show these technologies are available COTS with little or no modification. For each of the approaches, one or more examples of COTS items were identified in a non-exhaustive search. This suggests the general availability of the associated key technologies; however, at least the following should be considered when using any of these approaches for chemical level measurement for the SCSS application. Please note this list is not exhaustive and is preliminary.

- Flowrate and time measure (primary)
    - Software needs to integrate data over time for current level reading and hence store data
- Load plate at HOLD/bladder interface
    - Bladder chemical outlet and load plate in close proximity will best reflect remaining accessible chemical in bladder (e.g., they are both “blind” to high-side volumes caused by non-zero trim)
    - Distributing more load plate sensors will reduce volumes “blind” to sensor (see above)
    - Layout load plate system to verify packaging reasonable
    - Smooth soft cover overload plate to mitigate shock loads from impacts and to mitigate risk of damage to bladder for transit and vibrations
    - Protection of load plate from heavy loads prior to HOLD “closure” (e.g., bladder installation)
- Linear Position Sensors between HOLD and bladder
    - Packaging of LPS within HOLD may be challenging, layouts should be done
    - Smooth soft cover over LPS to mitigate risk damage to bladder for transit and vibrations
    - Secondary positive locking of microcable connections between bladder and sensor
    - Bladder control stiffeners/plate similar density as bladder to mitigate dynamic/vibration “nibbling”, damage long-term
- Linear Collapsible Contact Pressure Sensor System
    - Vented pressure sensors likely more compact (e.g., dP sensor will not use on side – vented)
    - Fill compressible hose such that the temperature, pressure, and other effects do not allow its liquid contents to overload pressure cell or affect measurements
    - Temperature and pressure corrections for compensation for fluid expanding and contracting

- Level/Pressure Sensor System on bladder and / or HOLD plumbing
    - Vented pressure sensors likely more compact (e.g., dP sensor will not use on side – vented)

13.3 Validation

Critical Component Testing Protocol

Cost-share work and experience from the fabric manufacturers and bladder fabricators was a critical start-point. Additional reports and data provided as cost-share by Baker Hughes was also of great value. Additional work SMT performed in validating the earlier work is outlined below.
For a complete catalogue of work performed, please refer to Appendix 3.

Argen Polymer LLC; Fluid Compatibility Validation (excerpts from Argen report)

Compatibility Screening Tests
From your information about the application, we characterize the material requirements in the Figure 54 below.

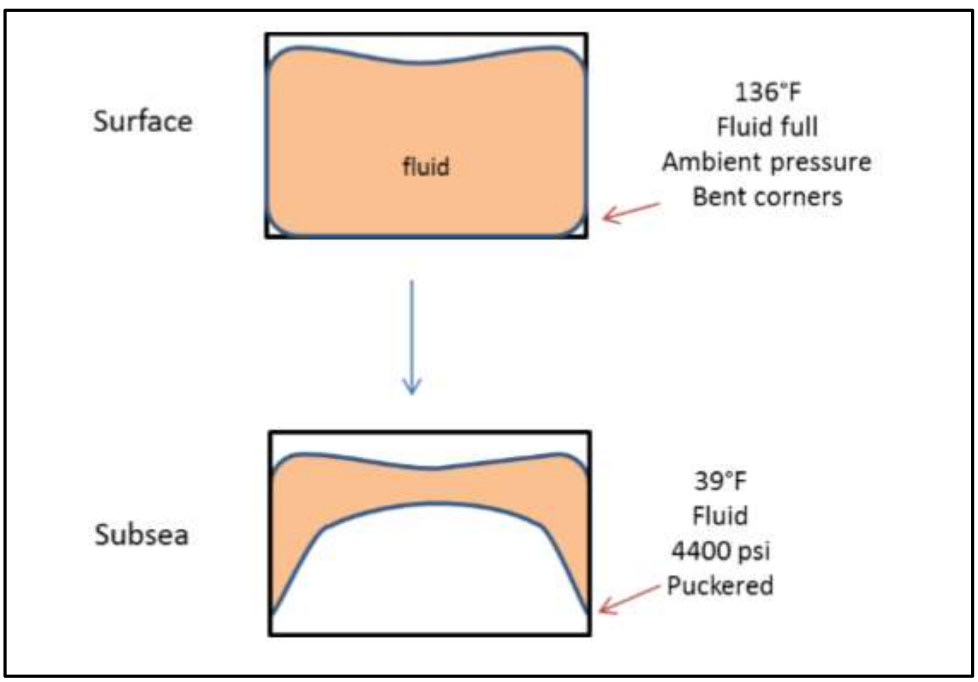


Figure 52: Material requirement ranges

To address this type of service the following exposures to assess progressive degradation caused by fluid, by heat and by mechanical strain:

- 28-day fluid aging with sampling at 7, 14 and 28 day intervals

- 136°F fluid temperature
- Aging pressure to be nitrogen blanket of ca. 200 psig. This pressure is only intended to suppress vaporization of the fluids. In the application, the bladder will never be subjected simultaneously to elevated temperature and pressure (see above). While aging under pressure would accelerate permeation of fluid into the materials, we believe that doing so would unnecessarily increase the cost of the screening for little technical benefit.
- An additional set of specimens to be aged in a strained configuration as shown below in Figure 55.

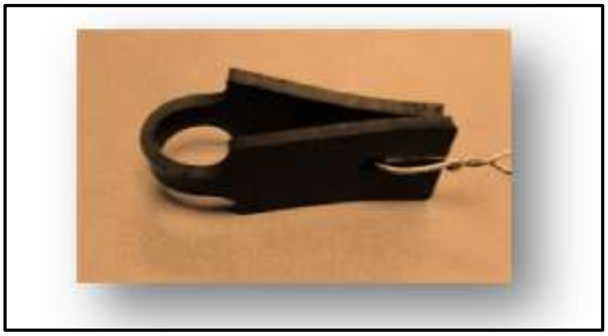


Figure 53: Material test configuration

The test plan detailed in Table 2 below includes stress-strain measurements to be made in two orthogonal directions to address the two-dimensional deformations experienced by the bladder in use.

Test	Applicable Standard	Test Specimen	Strain Direction	Replicates
Uniaxial Tension	ASTM D1708	3" Dogbone	Parallel	3
			Transverse	3
Uniaxial Tension	ASTM D1708	3" Dogbone, Bent, 28 day exposure	Parallel	3
Mass Change/ Volume Swell	ASTM D471	3" Dogbone	-	3
Hardness	ASTM D2240	3" Dogbone	-	3
Abrasion	Taber	0.080"x 4" dia circular sheet	-	3
Visual	-		Inspect for cracks, voids, tears etc.	

Table 2: Material test parameters

A set of 3 specimens will be analyzed by all tests at each of the three intervals. We propose combining materials for aging in a single vessel; this will significantly reduce the cost compared to employing separate vessels for each material. There is a recognized risk of cross contamination amongst materials in taking this approach, but in our experience this risk is minimal.

ISO 23936-2 is a standard used throughout the oil and gas industry for assessing fluid compatibility of non-metallics. We propose following the guidelines therein for the present study for acceptance criteria as well as long-term aging and life estimation. The purpose of the initial screening is to compare and down-select material candidates for long-term testing. Bear in mind that it is not possible to definitively predict actual field performance from accelerated aging lab studies. We propose to rate material candidates as shown in Table 3 below. We estimate a timeframe of two months to completion after all materials and fluids have been received.

Property	ISO 23936-2 Acceptance	Full Pass	Conditional Pass	Fail
Tensile Modulus*	± 50%	≤ ± 25%	> ± 25% and ≤ ± 50%	> ± 50%
Ultimate Tensile Elongation	± 50%	≤ ± 25%	> ± 25% and ≤ ± 50%	> ± 50%
Ultimate Tensile Stress	± 50%	≤ ± 25%	> ± 25% and ≤ ± 50%	> ± 50%
Volume	+ 25%, -5%	+ 25%, -5%	-	+ 25%, -5%
Hardness, units	+10 , -20 units**	≤ +10 , ≤ -20 units	-	> +10 , > -20 units

*At 50% elongation for rubbers, at 10% elongation for coated fabrics.
**+5, -20 for initial nominal hardness 90

Table 3: Material acceptance criteria

Appendix 3 details out the results of the material – chemical testing.

Long Term Aging Tests

Section 7.2 of ISO 23936-2 details methods for life estimation testing based on accelerated aging. This approach is based on the use of elevated temperature to accelerate chemical interactions between the material of interest and the fluid/gas environment employed for the aging. First order chemical kinetics (Arrhenius) are used to model degradation of properties over time, and further to mathematically interchange temperature for time, enabling extrapolation out in time at lower temperatures. Because this approach is chemical in nature, only chemical interactions are addressed. Such a model should not be interpreted to address application specific features other than the chemical environment, such as stress geometry or strain amplitude, frequency of deformation, etc. There is therefore no implication of a guaranteed useful life in the actual application.

Life estimation requires aging materials at minimum three (3) temperatures, which will be determined based on the screening results. Specimens are extracted for measurement at multiple intervals during the aging so as to generate a rate curve, enabling identification of a time-to-failure based on the criteria in Table 3 above per ISO 23936-2. These time-to-failure points are then used to generate Arrhenius plots from which life estimation at various temperatures is derived. Herein, we have assumed a maximum aging duration of ninety (90) days, with varying intervals depending on the temperature. Should adjustment of time or temperature parameters be necessary based on early results, Safe Marine Transfer LLC will be consulted.

Scale Model Test Apparatus

To validate the mechanical performance of the bladder and determine likely 'residuals' after full pump-down, a scale model test apparatus was conceived, designed, engineered and built.

Bladder Tank Test Objectives.

Overall objectives:

- Minimize anticipated (observed) bladder chemical retention
- Repeatability of bladder collapse / fill
- Impact of variables; rates, attachment points, SG differences, tilt, material

1. How does the bladder collapse when filling and emptying?
    a. Does the bladder's collapse/refill pattern seem detrimental or have associated high stresses?
    b. What is the impact of fluids with different specific gravities? Trend pressures in bladder and hold as the bladders are filled and emptied.
    c. Does the bladder port fitting impact the filling or emptying of the bladder?
    d. What is the general retainage when emptying the bladder?
    e. What is the amount of barrier fluid in HOLD when the bladder is full? Is there a difference between the two bladder designs and is this significant?
    f. Does the bladder construction seams have impact on the collapse response of the bladders?
    g. Is there an impact on bladder behavior if the hold model is tilted to a 10 degree slope?
    h. Does inverting the bladder so the fill line is from the bottom of the bladder offer any advantages?
    i. Is there significant differences in the plastic vs the elastomeric coated bladders.
    j. Does it appear feasible that sidewall pressure sensors would make viable bladder fill sensors? Does the bladder bear against the HOLD sidewall as it is filled?

2. What is the impact upon bladder collapse with different wall attachment points (Top, Middle or Bottom)? Note: This response is expected to be a function of the fluid Sg differences
3. Define the HOLD & Bladder Interaction:
    a. Does a half full bladder have any potential "sloshing" observed when the model is slightly moved? If this occurs, it is expected when the bladder and barrier fluid Sgs have the largest differential.
    b. Does the bladder tend to float to the top, sink to the bottom or remain in place? Is this a function of fluid Sg (Expect bladder material to have a Sg ~0.9)?
    c. Is there an improvement on the bladder/hose connection within the hold?
    d. Does the barrier fluid discharge port need piccolo tubes or a cage to prevent the bladder from sealing off the port during a bladder refill operation.
4. What is the impact of attaching a stiffener plate (plastic) on the bottom of a bladder during fill and emptying?
    a. Does this look like a viable way to monitor the bladder fill volume?
    b. Does the mass of the stiffener look like it would move in a dynamic seaway? If the stiffener had a Sg close to seawater does that impact the dynamics? Plastic sheets range from a Sg of about 0.9 to 1.3.
5. Other unplanned tests or repeats.
6. Marketing Demonstrations

Testing Parameters

- Two bladders of different materials from 2 different manufacturers. (One black plastic coated fabric from Aire and one tan elastomeric coated fabric by Avon.)
- Two bladder port Orientations – topside or bottom side up.
- Three bladder attachment points (top, middle, bottom)
- 4 test fluid combinations of brine and fresh water: (brine at 1.1 and 1.2 Sg)

	Bladder Fluid	Barrier Fluid	Remarks
Condition 1	Sg=1.0	Sg=1.0	For Chemicals near the Specific Gravity of water
Condition 2	Sg=1.0	Sg=1.1	For simulating Chemicals with a Sg of ~.9
Condition 3	Sg=1.0	Sg=1.2	Simulates Methanol in the bladder
Condition 4	Sg=1.1	Sg=1.0	Simulates Glycol in the bladder

Note: The important fluid aspect is the difference in Specific Gravity rather than the absolute value. It will be important to pull fluid samples and test Sg in system to maintain density control.

Test Model Schematic and Engineered assembly

See Figure 56 below, for the schematic and Figure 57 for a portion of the engineered HOLD assembly.

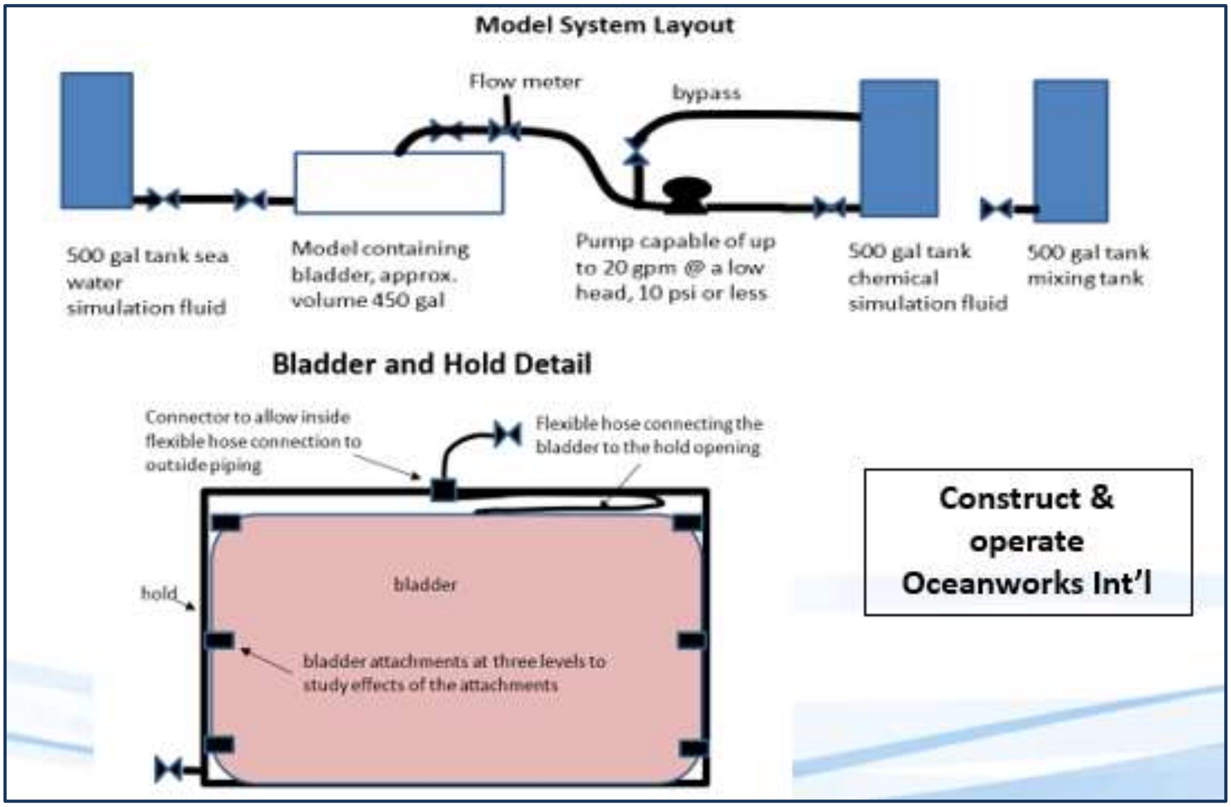


Figure 54: Scale Model Test Apparatus - schematic

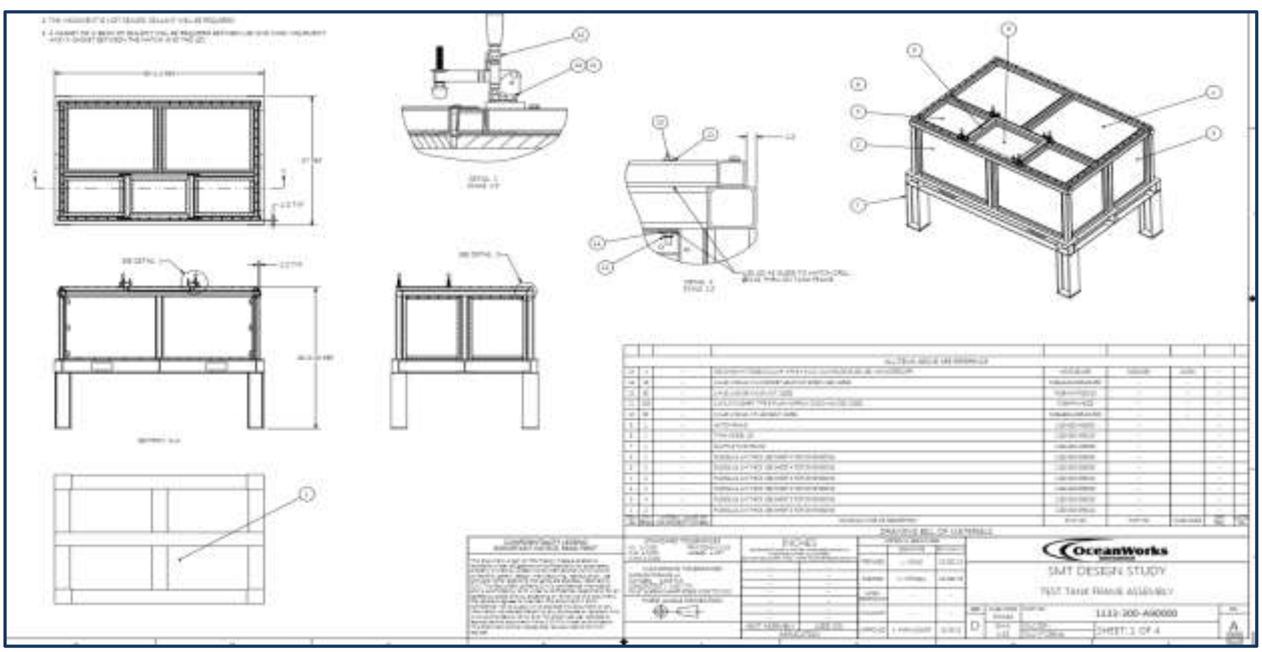


Figure 55: Scale Model Test Apparatus - engineered drawing

Scale Model Test Apparatus in Operation


Figure 56: Scale Model Test Apparatus – with bladder inserted

Figure 57: Scale Model Test Apparatus – assembled and in operation

These figures 58 – 61 illustrate the experimental set-up of a 1/5th scale model HOLD (with plastic sides, top and bottom) and the scale bladder. Testing has not discovered any mechanics that are detrimental to integrity or life of the bladder. Preferred installation configuration and the value of certain internal components have been determined. The complete testing plan and experimental results are documented in Appendix 4.

Figure 58: Test Apparatus with holding and pumping tanks

Figure 59: Test Apparatus with holding and pumping tanks

Scale Model Test Apparatus, Observations and Conclusions

- The inflation and depletion patterns were remarkably consistent during repeated tests. One of the more important conclusions of the testing is that bladder behavior as SMT configured resulted in consistent and orderly collapse and fill. No excessive creasing or folding that might lead to a wear / weakening of the bladder material was noted for both the elastomer and plastic bladder material. In general, the bladders deplete by folding in toward the bladder exit port and away from the hold walls.
- The present recoveries of the simulated chemical from the bladder ranged from a low of 60% to over 90%. The major limiting factor for the per cent recovery was the fact that the bladder fabric would press up against the bladder port and cut off flow. Future work will include improved bladder design, optimizing the relationship between the bladder outlet(s) and the stiffer areas of the bladder.
- The location of the bladder port will impact overall recoveries. A number of ideas for potential improvement were noted.
- The collapse characteristics were generally the same between the elastomer bladder and the plastic bladder at the scale of the test. The elastomer fabric is stiffer than the plastic fabric bladder. In the comparison tests done with the middle attachments to the hold, the more flexible plastic bladder demonstrated slightly better behavior as it collapsed, in that the bottom of the bladder moved up in a more piston like manner as compared to the more bowed, or dome shaped, bottom seen with the elastomer fabric.

- Test were done with two differential specific gravities, 0 and .2. Based on these tests, the behavior of the bladder under the higher specific gravity differential was more controlled and was less sensitive to the pressure differential imposed by the suction of simulated chemical from the bladder. The 0.2 S.G. differential is slightly less than that between seawater, 1.03, and methanol, .79, or .24.

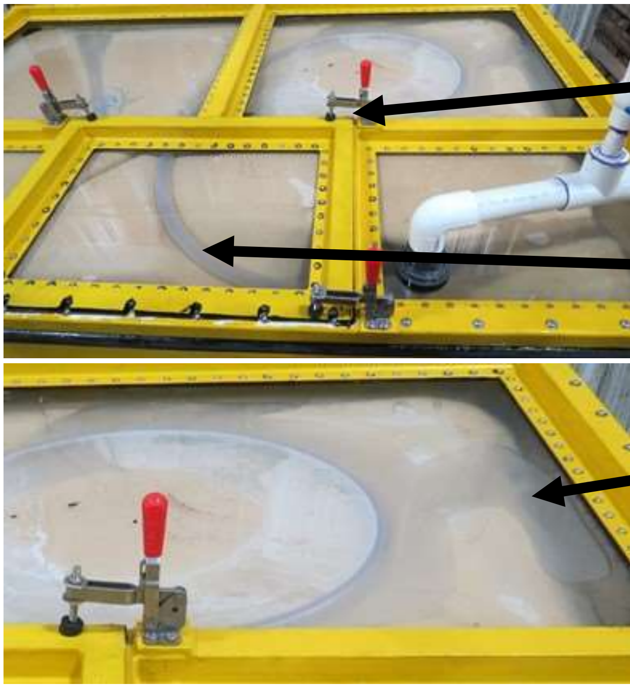
An elastomer bladder was the first bladder tested (see Figure 62). When the bladder was initially filled, there was air in the bladder. The bladder was attached at the midpoint of the hold. As much air as possible was removed by filling and purging, however, there was a small amount of air that was unable to be removed. This fact influenced the bladder behavior to some extent, especially during the first tests.

It was completely filled to its measured 390 gal maximum volume. The initial tests were done with a 0 specific gravity difference between the simulated chemical and the simulated seawater. The specific gravity of the simulated chemical was 1.0, using fresh water for the chemical simulation. The specific gravity of the simulated seawater was also 1.0, again, using fresh water for the seawater simulation.

This shows the elastomer bladder, nearly filled, within the model of the hold. The bladder has a port at the top center of the bladder and is attached to the hold at the midpoint of each of the four corners of the hold.

Figure 60: Elastomer bladder tests

Below in Figures 63 through 65 can be noted various aspects of the Scale Model Test Apparatus in testing mode.



This shows the top view of the bladder and hold. The smaller panel with the separate clamps is a scale of the hatch that will be in the hold.

The flexible hose from the bladder port to the exterior of the hold can be seen.

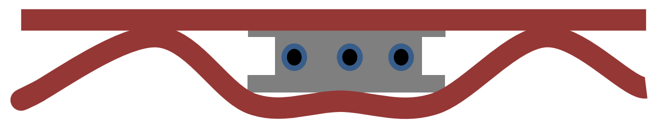
Also, evidence of some air in the bladder can be seen.

Figure 61: Aspects of the Scale Model in test mode

This shows the bladder as it is being depleted. The bladder creates a dome on the underside. The corners of the bladder are the last to move up due to their extra stiffness and the attachment points at the midpoint of the hold. There is some residual air in this bladder during this depletion.

Figure 62: Bladder during depletion mode

This is a view of the bladder from the bottom. The bottom of the bladder is sucked up to the port on top of the bladder. There, the bladder fabric closes off flow at the port. There was a special port on this bladder with some amount of bypass capability, however, the fabric eventually folded up against it and shut off flow.



Schematic of the profile of the bladder port showing holes for flow if bladder fabric is pulled up to the port bottom. The design was the limiting factor in the percentage depletion that was achieved.

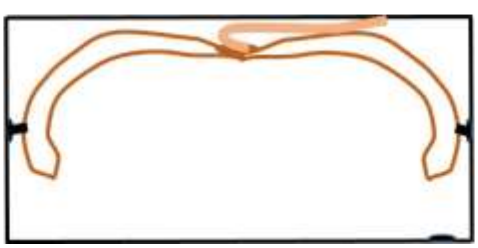
Figure 63: Bladder during depletion - bottom view

Tests of fill and depletion were then run using fresh water as the simulated chemical, S.G.=1.0, and saturated saltwater as the simulated seawater, S.G.=1.2. This provided a differential S.G. of 0.2 between the simulated chemical and the simulated seawater.

The schematics below in Figure 66 through 68 provide a simplified view of the photographs in figures 63 through 65 above.

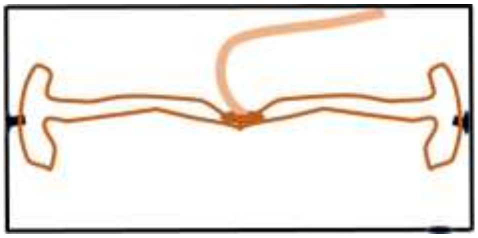
Schematic Cross Section of Hold with Full Elastomer Bladder

Figure 64: Schematic - corresponding to photo Figure 63



Schematic Cross Section of Hold with Depleted Elastomer Bladder. Shown as depletes when there is residual air in the bladder.

Figure 65: Schematic - corresponding to photo in Figure 64



Schematic Cross Section of Hold with Depleted Elastomer Bladder. Shown as estimated to deplete when there is no residual air in the bladder.

Figure 66: Schematic - corresponding to photo in Figure 65

14.0 Shuttle Design and Performance

During Stage 1 the SMT team assisted by Alan C. McClure Associates (ACMA) conceptualized a number of different installation scenarios for a safe, reliable, and cost effective methodology and generated operational storyboards and concepts for review and selection of the preferred methodology (See figure 16). After considerable analysis a dual catenary system ‘balancing’ the positive buoyancy of the shuttle with the weight of the catenary wire (or rope) and chain was selected.

The chemical cargo provides significant variable buoyancy to the shuttle system (especially Methanol.) In Stage 1 the design used a heavy shuttle and used the compressed nitrogen in the HP composite tanks to reestablish a positive buoyant condition for an empty (seawater filled) shuttle recovery. There were a number of issues with this concept that prompted a Stage 2 design revision. The Stage 2 revision maintains the composite tanks sealed and any chemical buoyancy is offset with steel ballast blocks mounted on the shuttle deck. The ROV support vessel recovers the required number of ballast blocks to trim the shuttle to its positive buoyant condition before shuttle recovery. Operationally, this is an improvement over the prior design.

A second Stage 2 concept change was associated with the size and number of chemical bladders. A single bladder (although feasible) has little flexibility, high initial cost and handling issues. This led to the decision to use 3 x 1100 bbl bladders. They are easier to fabricate and handle. Further, they add flexibility in that multiple chemicals may be simultaneously deployed.

Development of the Stage 2 shuttle with these changes, its operation and its analytical validation are described in the following. The detailed shuttle design information are included in Appendix 2.

14.1 Project requirement

Deliverable: Shuttle Design Report and a CFD Analysis Report

Description: ACMA developed the shuttle concept in Stage 1 and in this work will mature the design to the point that securing a quality shipyard cost estimate for the shuttle will be feasible. This work includes:

- Analysis of design issues and concerns will include the following:
    - Computational Fluid Dynamic Analysis (CFD) will be used to predict with precision the behavior of the submerged shuttle during installation and production operations. The calculated loads will be used to refine the shuttle's design. This analysis will verify the shuttle's performance and replace the originally planned wave tank tests with a better simulation process.
    - High Pressure Composite Tanks for buoyancy will be reviewed in detail with their manufacturer for this repurposed application. This is a design quality assurance process. Piping and operation of the High Pressure (HP) buoyancy is included.
    - Develop the functional specification of the chain winches and their operation so that vendors may provide designs and proposals to provide this equipment.
    - Structural analysis of the shuttle and optimize shuttle strength and weight.
    - A foundation analysis and design for the Gulf of Mexico (GOM) design site. Different foundation features may result, depending upon the soil strength and currents.
    - Design and procedures to minimize any people safety exposure in all phases of operations.
- Develop all interface definitions for shuttle. This includes all equipment, fittings, panels, hatch requirements, piping, etc. required to complete the shuttle system and make the structure a functional system. This information will be captured in the project documentation.
- Work with Canyon Offshore to understand all planned operations to confirm that fittings, components and functional capabilities exist on the shuttle design to safely accomplish the planned operations.
- Participate with Canyon Offshore in a risk reduction process, including a DFMEC A, Hazid and HazOps of the developed design and its planned and contingency operations.
- Along with SMT, work with classification societies toward obtaining an "Approval in Principle" of the shuttle's design and operation. Further, assist in regulatory meetings to confirm that the system is Regulatory Agency acceptable and appropriate for GOM use.
- Develop a shuttle construction contracting strategy considering shipyard capabilities.
- Complete the design package consisting of drawings, specifications, and design documents.
- Perform project routine reporting, presentations, and conduct of meetings.

This work is focused on providing the shuttle as a functional and qualified design that may be shipyard cost estimated.

14.2 Project Results

Executive summary (143-page report in Appendices)

The Shuttle's function is to deliver production chemicals from dockside to the ocean floor / point of use and return to dockside; all in a safe, reliable, repeatable and economic fashion. It is designed to deliver a net volume of 3,000+ bbl of any of several production chemicals. All of these chemicals are in use today, but are classified as hazardous from a regulatory point of view. Hence the Shuttle is specifically designed to ABS Rules for Hazardous Cargo Barges and Emerging Technologies. The Shuttle includes a double hull providing isolation and protection to the SCSS.

The Shuttle is of standard steel construction with four columns protruding above the deck (Figure 69). The four columns are internally fitted with flotation elements, thereby raising the underwater center of buoyancy above the unit's vertical center of gravity. This configuration will provide stability during the lowering and raising of the Shuttle through the water surface and while transiting through the water column across a wide range of met-ocean conditions (Cooper, 2014). The current design water depth is 5,000 feet with the intention of additional future validation to allow for use in water depths up to 10,000 feet.

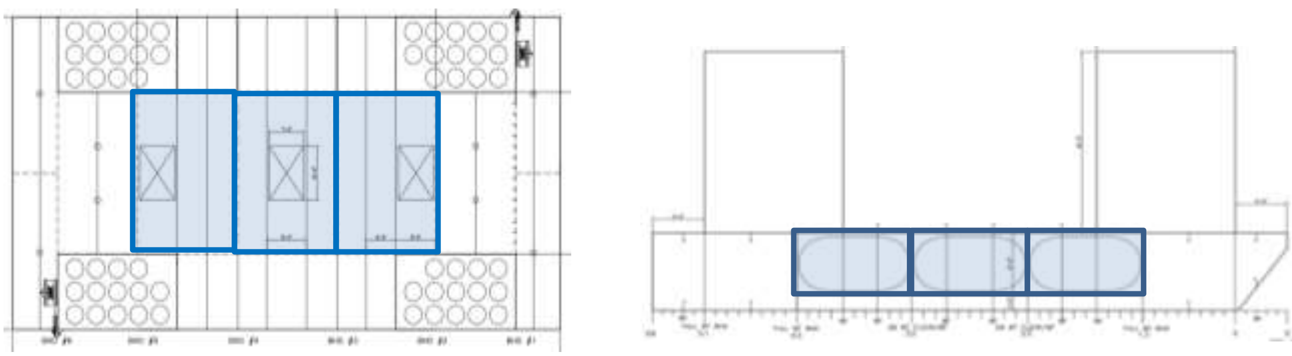


Figure 67: Shuttle showing Subsea Chemical Storage System (SCSS) payload

Hull Design

The structure of the barge is designed to ABS Steel Barge Rules to provide the basic structural design. Global bending and shear strength was checked to ABS Steel Barge Rules for Stillwater bending and shear stresses and to ABS Steel Vessel Rules less than 90 meters for wave loading. Global bending and shear strength in both the longitudinal and transverse directions were analyzed for shear and bending when the Shuttle is fully submerged. The column design was analyzed to verify that they have sufficient strength to support the shear and bending moment that would occur in the worst case scenario that the submerged barge should take an attitude of 90 degrees in the transverse or longitudinal direction. The column design was also checked for wind loading to ABS MODU Code. Buckling checks were applied in plating where there was any significant potential for buckling. Note that the double-sided and double-bottomed hull provides protection for the bladder and contained chemical in the unlikely event of a collision or grounding accident.

Topsides

Sufficient clear deck space and structural support is provided for topside payload / equipment. The Shuttle is designed to carry up to 60,000 lbs. of topside equipment. This load is assumed to be within an 8'x 8' x 20' ISO module frame but could be varied depending upon need. The Shuttle also has the ability to attach a small (<200 bbl) deck tank to store low volume use chemicals. This tank is assumed to be an 8' x 8' x 40' module that, when submerged, is almost neutrally buoyant. One, two, or more of these deck tanks (depending on size/volume and chemical specific gravity) may be installed and recovered with the Shuttle. Alternatively, the deck tanks may be installed post Shuttle deployment with the Shuttle as a foundation.

High Pressure Buoyancy Design

To provide buoyancy for the Shuttle, carbon fiber cylinders are utilized. These provide the most efficient and cost effective buoyancy for deeper water depths. Per the manufacturer the cylinders have a working pressure of 3,626 psi and a max fill pressure of 4,714 psi, thus allowing the future possibility of using this buoyancy technology in 10,000 feet water depth applications. These cylinders have already been certified by ABS, in conjunction with the U.S. DOT, for the transport of compressed natural gas (CNG) on U.S. highways.

For application in the Shuttle, the cylinders will be filled with nitrogen, as opposed to air, to avoid any potential risks of using oxygen under high pressure. As the Buoyancy Cylinders expand radially and longitudinally when pressurized, they are supported on their ends. One end is fixed while the other end is only supported perpendicular to the cylinder's longitudinal axis to allow longitudinal growth or contraction of the cylinder in different pressure environments (Figure 70).

Figure 68: High pressure composite buoyancy cylinders

Water Column Transit System

A system of polyrope, chain and connectors are utilized in the Shuttle deployment and retrieval process. Unlike a traditional platform mooring system, the chain in the Shuttle system is used for weight and control, not for ultimate strength. The chain is a standard 3" Stud Chain with 600' of deployable chain on each end of shuttle with a total net submerged weight for both at 88,000 lbs. Standard shackle and padeye connections common in mooring systems are used. Winches are used to deploy or to pull these chains aboard the Shuttle during operations. The Chain Catenary serves two functions;

1) Disconnects or decouples the motion between shuttle and surface vessel

2) Allows the mass of the shuttle to be adjusted during transit through the water column to control ascent/descent speed

Additional discussion is included in the transportation, deployment and retrieval section.

Winches

The Shuttle design is equipped with a winch on both its forward and aft ends. The winches are capable of handling the free hanging submerged weight of 600 feet of 3" studded chain (51,000lbs dry – each end). The winches are powered using a hydraulic stab from either the ROV or the work boat. As a typical work class ROV is rated between 150 and 250 HP, and the maximum capable output is 85% of these values; the winches are designed for a maximum power supply of 127 HP.

Foundation / Securing to Seafloor

Using soil data for the Gulf of Mexico (Fugro, 2014), the on bottom condition of the Shuttle was analyzed to determine if some form of mechanical anchoring, such as pin piles, were needed to prevent current forces from moving the Shuttle on the seafloor. Analyzed against the maximum current speed of 2.43 knots (1.25 m/s) – (velocity corresponding to the topographic Rossby waves generated by a 100-year event for a Gulf of Mexico installation in 5,000 feet of water), CFD analysis determined that no equipment such as pin piles or shear skirts are necessary.

Piping Systems

The Ballast System piping runs are specified to fully flood all of the Shuttle's compartments to submerge the Shuttle below the water's surface. Pipe and valves are sized to provide a controlled rate of sinking while minimizing pressure head on the tanks. Remotely operated (design completed for both hydraulic and electric) gate valves are specified for ballast hull penetrations to allow positive closure of compartments during surface transit.

All compartments are fitted with vents sized to prevent buildup of internal pressure due to the maximum filling flowrate. Each vent is fitted with a closure valve to allow compressed air to be used to deballast the compartment once the shuttle is recovered to near the surface.

Piping for the cargo system is to be kept to a minimum. The cargo piping system consists of a universal flanged connection at the deck to allow flexibility in pipe size depending on the chemical being used and its desired flowrate.

Instrumentation

The design includes instrumentation for monitoring the condition of the Shuttle and its various systems (i.e., valve positions, roll and pitch of Shuttle while submerged, cylinder pressure, etc.). Instrumentation between the Shuttle and process systems will interface through a "standard" interface flange and port through which all required process instrumentation may be added and linked back to the SCIU controls. Not all instrumentation will be remotely reported back to the hub facility. ROVs can observe valve positions, pressure gauges, etc. The system is to be kept simple, maximizing use of a ROV (or AUV) for data collection. Remote Instrumentation will be limited to items that require real time information and / or control.

14.3 Shuttle Structural Analysis

Executive Summary (Summary of 132-page report in Appendices)

Safe Marine Transfer, LLC (SMT) operating under a contract with RPSEA engaged Alan C. McClure Associates, Inc. (ACMA) to provide naval architect consulting and design services for the development of the Deepwater Chemical Storage and Delivery System project.

The project objective is to develop a recoverable system to deliver large quantities of well head chemicals to subsea fields. ACMA's responsibility is the Shuttle – the vehicle that delivers the chemical reservoir from dockside to the ocean floor and returns to dockside; all in a safe, reliable, repeatable and economic fashion.

The Shuttle is to be a barge of fairly standard steel construction with four columns protruding above the deck. The four columns are fitted internally with flotation elements, thereby raising the underwater center of buoyancy above the unit's vertical center of gravity. This configuration will provide stability during lowering and raising of the Shuttle through the water surface and the entire water column.

Part of ACMA's design work includes the structural design of the Shuttle and the structural analysis of that design based on 1st order principals. The purpose of this structural analysis is to provide sufficient structural analysis to prove that the structural design meets ABS Criteria so that ABS Class can provide an Approval in Principal Letter for the chemical delivery Shuttle. Along with the Approval in Principal ABS Class will provide SMT with a Road Map to what additional analysis is needed to obtain Class Approval of the Shuttle's structural design.

The following work was performed and is reported within this report:

- ABS Minimum Scantling Calculations for barges
- Global Longitudinal Shear and Bending Strength Analysis
    - Floating Conditions for various cargos
    - Submerged Conditions for various cargos and chain payout
- Global Transverse Shear and Bending Strength Analysis
    - Submerged Conditions for various cargos
- Wind Loading on Column
- Structural Strength of Column if submerged shuttle rolls or pitches 90 degrees
    - Includes plate panel buckling check for main deck around column and column panel buckling
- Structural Analysis of the structure which supports the buoyancy cylinders
    - Shuttle floating analysis with cylinder weight and vertical accelerations
    - Vertical Buoyancy Load for submerged shuttle

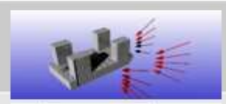
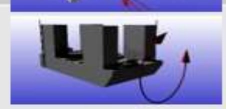
- Buoyancy Load if shuttle rolls or pitches 90 degrees
- Uneven load distribution on shuttle's hull at seafloor

The conclusion of the analyses performed is that the Shuttle design is fit for purpose within the expected operational envelope. It has sufficient longitudinal and transverse strength to withstand all of the bending moments and shear forces it is predicted to experience from the loading cases analyzed in this report.

The calculations also demonstrate that there is acceptable structural integrity for the structure supporting the buoyancy cylinders and columns.

14.4 Four (4) Phase Computational Fluid Dynamic (CFD) Study.

A four (4) phase CFD study was conducted to thoroughly investigate the Shuttle's stability across a wide range of conditions (Figure 71). CFD was used to explore operational boundaries of the submerged Shuttle in ways that are not possible with physical wave tank models. Operating limits were 2 knot currents from any direction and vertical transit speeds (up or down) 0f 0.5 knot while under full position control of the two surface vessels using the shuttle chains.

Phase	CFD Setup	CFD Results	Status	Picture
1	Steady Flow Analysis	Overturning Forces	Complete	
2	Forced Shuttle Motions	Damping of Shuttle Motions	Complete	
3[1]	Free Rotation of Shuttle	Evolution of Shuttle Forces	Complete	
4[1]	Full Ascent	Full System w/ Lowering Lines	In Progress	

1 = Laminar Flow physics (still have viscosity)

Figure 69: A set of comprehensive CFD studies were conducted on wide range of potential conditions

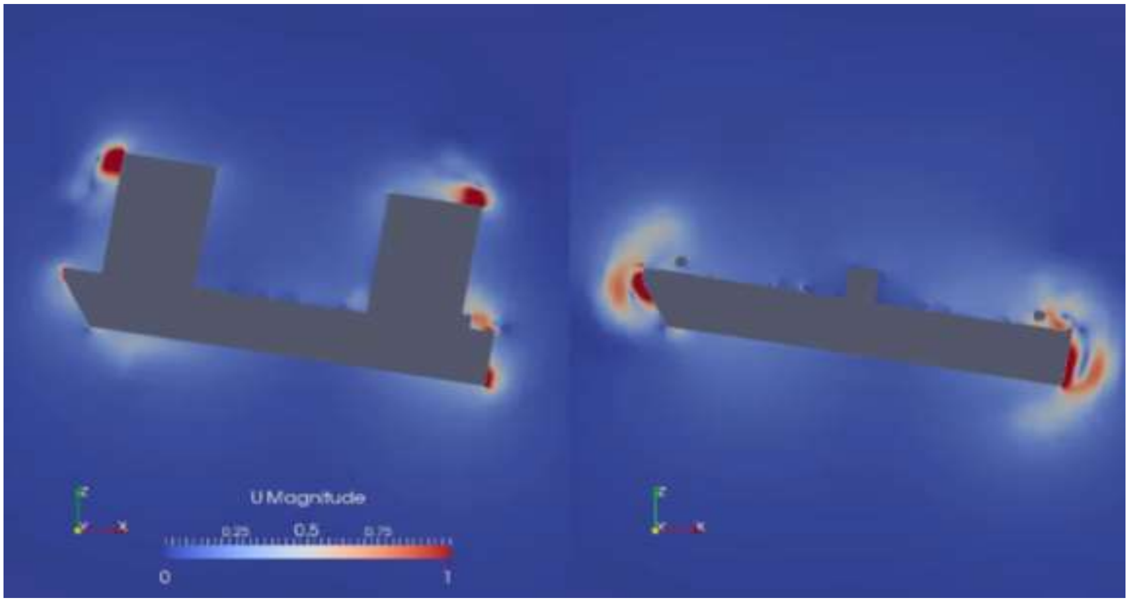


Figure 70: Example of velocities magnitude in slicing planes on centerline

Answers to key questions

- Will the Shuttle remain stable? Yes, from the analysis of the CFD (see graphical output example in Figure 72) the Shuttle remains upright while submerged in swift currents and does not require lowering lines to remain in acceptable catenary.
- Will shuttle rotate? How much? Results show negligible rotation. Lowering lines only control position, Shuttle stays upright during transit to/from seabed
- Will 'flutter' be a problem? The shuttle is highly damped subsea and consequently will not flutter (oscillate) during installation. The damping further enables seafloor positioning of the shuttle with projected good performance.

The hydrodynamic parameters were fully defined in the CFD analysis program. These important properties were exported into the GRI/DSA Prometheus empirical software. The Prometheus (laptop software) model and the CFD (mainframe) model were benchmarked and then used to validate the planned shuttle operations.

Following are excerpts from the four phased CFD study.

Alan C. McClure Associates, Inc. (ACMA) performed a series of computational fluid dynamics (CFD) analyses to determine the behavior of the Subsea Chemical Shuttle for Safe Marine Transfer, LLC. (SMT). The goal of these analyses was to predict the shuttle stability for a variety of conditions. ACMA proceeded with a four phase analysis.

Phase I – Static Force

Calculated fluid forces on the shuttle with the shuttled fixed in position and orientation. Calculated forces for bow, quartering, and beam currents.

Phase II – Forced Rotation

Shuttle fixed in translation and forcibly rotated. Calculated the damping due to shuttle motions. This measured the shuttle's ability to reduce its own motions. Shuttle was only free to rotate in pitch.

Phase III – Free Rotation

Shuttle fixed in translation but free to rotate. Shuttle subjected to incident ocean current and rotated in response. This checked if the shuttle stability would prevent rotation motions before overturning moments increased. Shuttle was only free to rotate in pitch.

Phase IV – Simulated Ascent

Shuttle was free to translate and rotate. Catenary lowering lines attached to shuttle. Shuttle subjected to incident ocean current and experienced translation and rotation in response. This checked the shuttle stability with all components interacting. Incident ocean current only applied in the transverse direction.

CFD PHASE I - DESCENT/ASCENT FORCES AND OVERTURNING MOMENTS (summary – 103-page report contained in appendices)

CFD Phase I

This report is specific to CFD phase I. The results of the other phases are contained in separate reports. ACMA completed a forces and overturning moment analysis on the Subsea Chemical Shuttle for SMT. This report summarizes the results of the computational fluid dynamics (CFD) analysis of the drag and overturning analysis for the Subsea Chemical Shuttle, as requested by SMT. The primary goal of this analysis is to show the static effects of water current on the vessel during its transition to and from the seafloor. This included all of the conditions detailed in **Error! Reference source not found.**4 below.

Validation efforts showed acceptable levels of CFD error for this analysis. This combined error from all sources was 3% for the forces and 5% for the moments.

Angle of Attack	Bow-On			Quartering			Beam-On		
(deg)	X Velocity *(m/s)*	Y Velocity *(m/s)*	Z Velocity *(m/s)*	X Velocity *(m/s)*	Y Velocity *(m/s)*	Z Velocity *(m/s)*	X Velocity *(m/s)*	Y Velocity *(m/s)*	Z Velocity *(m/s)*
-30	0.4455	0.0000	-0.2572	0.3150	-0.3150	-0.2572	0.0000	-0.4455	-0.2572
-15	0.4969	0.0000	-0.1331	0.3514	-0.3514	-0.1331	0.0000	-0.4969	-0.1331
0	0.5144	0.0000	0.0000	0.3637	-0.3637	0.0000	0.0000	-0.5144	0.0000
15	0.4969	0.0000	0.1331	0.3514	0.3514	0.1331	0.0000	-0.4969	0.1331
30	0.4455	0.0000	0.2572	0.3150	-0.3150	0.2572	0.0000	-0.4455	0.2572

Angle of Attack	Bow-On			Quartering			Beam-On		
(deg)	X Velocity *(knots)*	Y Velocity *(knots)*	Z Velocity *(knots)*	X Velocity *(knots)*	Y Velocity *(knots)*	Z Velocity *(knots)*	X Velocity *(knots)*	Y Velocity *(knots)*	Z Velocity *(knots)*
-30	0.8660	0.0000	-0.5000	0.6123	-0.6123	-0.5000	0.0000	-0.8660	-0.5000
-15	0.9659	0.0000	-0.2587	0.6831	-0.6831	-0.2587	0.0000	-0.9659	-0.2587
0	0.9999	0.0000	0.0000	0.7070	-0.7070	0.0000	0.0000	-0.9999	0.0000
15	0.9659	0.0000	0.2587	0.6831	0.6831	0.2587	0.0000	-0.9659	0.2587
30	0.8660	0.0000	0.5000	0.6123	-0.6123	0.5000	0.0000	-0.8660	0.5000

Table 4: Simulation conditions and associated velocity components

An initial hydrostatic submerged stability check was conducted using the moment coefficients transformed to be about the center of buoyancy. This initial hydrostatic analysis showed the vessel was stable at the maximum assumed descent/ascent rate of 0.5 knots and maximum current speed of 2.0 knots. The maximum total angle of inclination for bow-on flow was 1.61 degrees. The maximum total angle of inclination for quartering flow was 6.94 degrees and the maximum total angle of inclination for beam-on flow was 5.64 degrees.

The shuttle's susceptibility to sliding once on the seafloor was analyzed in a first pass analysis. The drag forces caused by a current speed correlating to a 100 year return period were shown to be one third of the shear capacity of the soil. The shuttle should be safe from sliding on the seafloor when appropriately placed. From these results, engineers determined further CFD simulations of this scenario were unnecessary.

Overall the analysis was successful, providing the force and moment coefficients induced by flow across the vessel at various angles of attack and flow orientations. **Error! Reference source not found.** shows an example of visualizations that are provided later in the report. The figure shows a representation of pressure on the coloring of the shuttle explained later in the report and streamlines indicating the complex flow around the shuttle and towers.

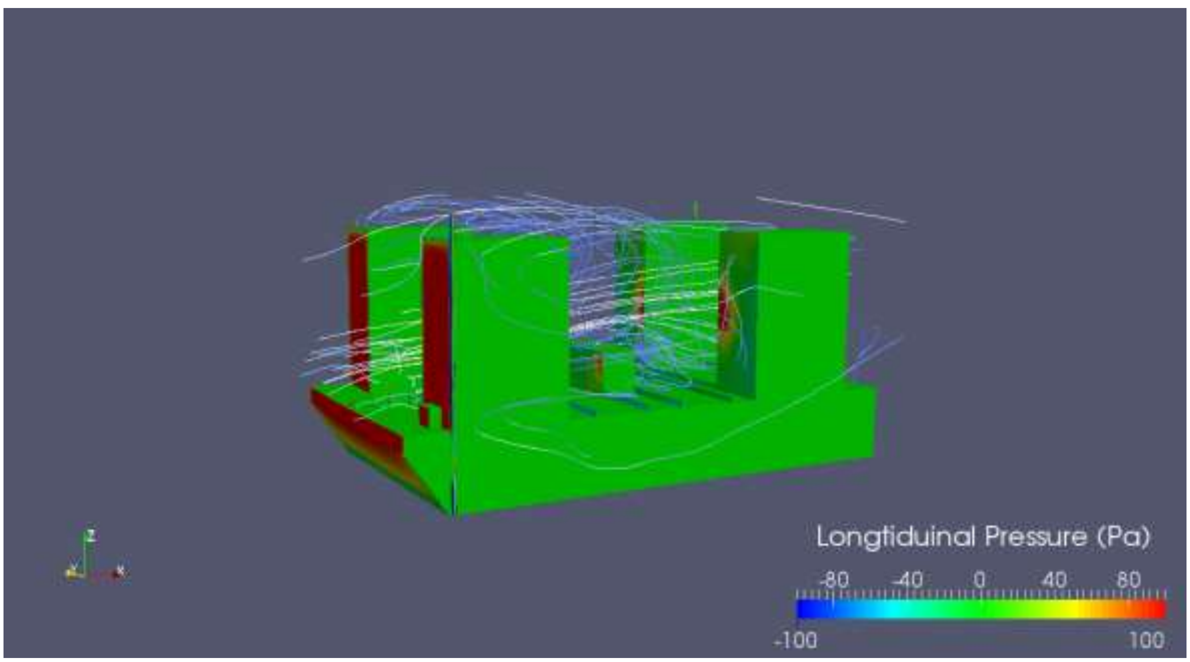


Figure 71: Example of pressure and stream line visualizations

CFD PHASE II - DAMPING UNDER FORCED MOTION (Summary of 80-page report contained in appendices)

This report is specific to CFD phase II. The results of the other phases are contained in separate reports.

ACMA completed a damping analysis due to forced oscillatory rotation motion on the Subsea Chemical Shuttle for SMT. The primary goal of this analysis was to show the damping ratio of the vessel during forced oscillatory pitch motion. The pitch direction was selected for damping because the metacentric height (GM) for a submerged body is the same in any direction. Due to this, restoring moment did not depend on the direction of rotation.

ACMA engineers then considered which rotation direction had potential for the greatest excitation moment. It was expected that a larger hydrodynamic moment would be created for pitch rotation due to the shuttle length. Five oscillation frequencies were tested for the pitching motion of the shuttle corresponding with ratios of 0.8, 0.9, 1.0, 1.1, and 1.2 of the pitching natural frequency.

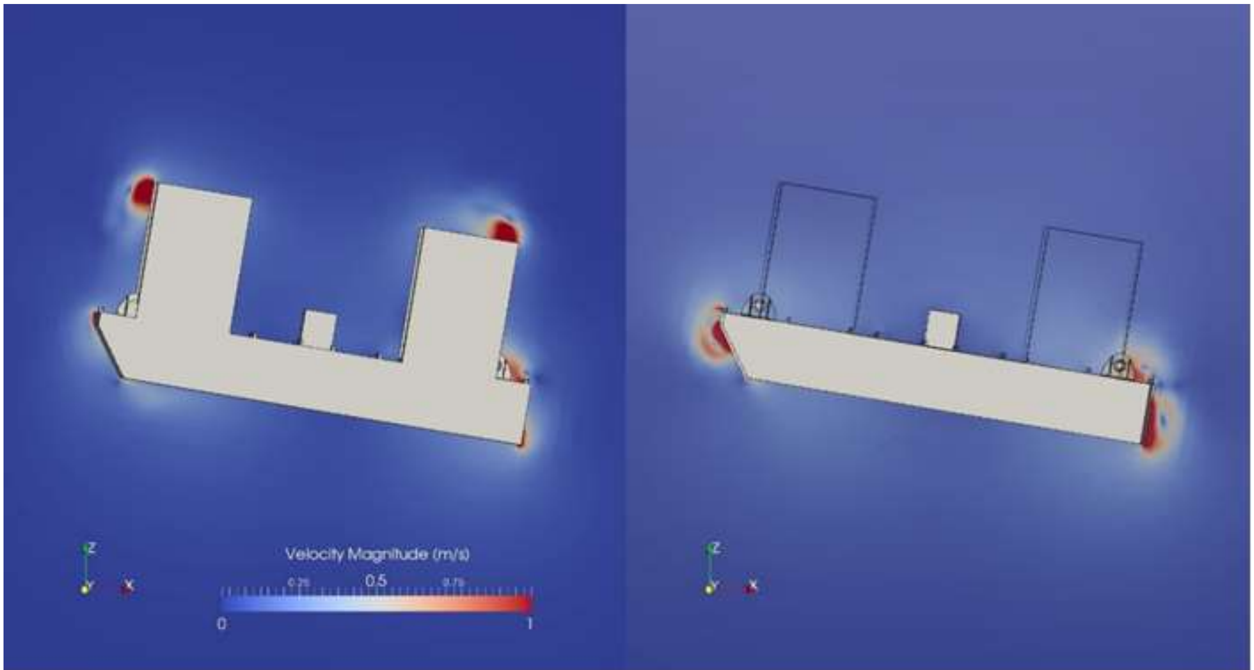
Validation efforts showed acceptable levels of CFD error for this analysis. This combined error from all sources was 8.8%. The analysis showed that the shuttle experienced super critical damping for the conditions simulated. **Error! Reference source not found.**5 presents damping ratios at each frequency.

Multiplier of Natural Frequency	0.8	0.9	1.0	1.1	1.2
Frequency (rad/s)	0.2582	0.2904	0.3227	0.355	0.3872
Damping Ratio	1.337	1.399	1.465	1.516	1.564

Table 5: Dampening ratio results

ACMA included flow and pressure visualization examples to explain the flow patterns around the vessel. **Error! Reference source not found.** shows an example of these visualizations. The figure shows the velocity magnitude in two different sections through the domain of the simulation at the same time step. Color indicates velocity magnitude, proportional to the legend included with the Figure 74. Overall the analysis was successful, providing the moment values necessary to calculate the damping of the vessel.

This report is phase II of IV and is intended to show the damping characteristics of the shuttle while submerged. Phase I showed the static underwater stability and ability to resist sliding on the seafloor. Further phases will investigate more complex dynamics such as fixed translation dynamic fluid body interaction (DFBI) and full six degree of freedom DFBI.



Longitudinal Section In Way of Buoyancy Towers 7 m (23.0 ft) Off Centerline	Longitudinal Section In Way of Centerline

Figure 72: Example of velocity magnitudes

CFD PHASE III FREE PITCH MOTIONS (Summary of 58-page report in Appendices)

This report is specific to CFD phase III. The results of the other phases are contained in separate reports. The CFD analysis simulated the shuttle free to pitch under the influence of a horizontal current and a fixed vertical velocity. The catenary lines were not modeled. This simulation primarily assessed the shuttle stability without the catenary lines. The phase III CFD analysis answered three key questions.

- How the rotating moment varied with the shuttle angle in a dynamic scenario. Previous work in phase I [1] only assessed this in a static situation.
- How damping reduced shuttle motions in a dynamic scenario.
- Whether the shuttle would remain stable in a dynamic scenario without the catenary lines.

ACMA engineers modeled the shuttle with a vertical velocity and a horizontal current velocity. Rather than vertically move the shuttle, ACMA applied a water velocity in the opposite direction. This is a common technique in fluid mechanics to model the steady velocity of an object. Two scenarios were investigated: one with the shuttle in the ascent condition, and one with the shuttle in the descent condition. Section **Error! Reference source not found.** lists the water velocities for these environmental conditions.

As the shuttle rotated in pitch, the hydrostatic moment increased. At the same time, the overturning moment due to hydrodynamic pressures changed. This overturning moment typically increased with pitch angle. One expects that at some point, the hydrostatic restoring moment matches the hydrodynamic overturning moment.

The shuttle did exhibit an equilibrium angle, which indicated positive pitch stability. This point of equilibrium was the critical output from the analysis. ACMA engineers previously estimated the pitch dynamic equilibrium angle based on results from CFD phase I, using static analysis. CFD phase III now examined the results in a dynamic analysis to determine any differences. **Error! Reference source not found.** compares the pitch equilibrium angle in the dynamic and hydrostatic analysis.

Item	Ascent Case	Descent Case
Dynamic Equilibrium Angle (RotY)	-0.027 deg	0.715 deg
Hydrostatic Equilibrium	-0.061 deg	1.583 deg
Hydrostatic Deviation	+130%	+121%
Hydrostatic comparison assumes a cargo of Methanol. See **Error! Reference source not found.**. Results include CFD error.		

Table 6: Hydrostatic comparison

The results compared very well between the static and dynamic analyses. This indicated that dynamic forces were not significant in shuttle motions. More importantly, the hydrostatic analysis was conservative. The values for hydrostatic equilibrium were larger in magnitude than the dynamic equilibrium angle. This demonstrated that hydrostatic analysis was a suitable simplification for future analyses of shuttle stability in the submerged condition.
ACMA engineers reviewed the CFD analysis and determined the following operational impacts for the shuttle.

- The shuttle can be regarded as essentially static in pitch rotation. It moved in very slow motions and reacted slowly to any changes in velocity during the simulation. Reaction times required minutes for the shuttle to show any noticeable change in orientation. There were several minutes to react to any change in flow conditions for pitch motions.

- The shuttle had good pitch stability. It remained nearly level in pitch rotation. The shuttle remained nearly level under the forces of the side current.

- Flutter was not a concern on the shuttle. It did not exhibit flutter in the simulation.

- The shuttle was super-critically damped for large amplitude pitch oscillations. [2] It did not rock back and forth if disturbed by an ocean current or other sudden loading. Any sustained oscillations indicated some imbalance with the cargo.

- Hydrostatic analysis was a suitable method for calculating stability and pitch angles of the shuttle for pitch motions. Dynamic analysis was only necessary for pitch stability in cases of extremely small safety margins. No such cases were currently identified.

- Fatigue concerns were very unlikely due to longitudinal forces. The longitudinal force on the shuttle oscillated by only 7.52% of the average force (including the safety factor for CFD errors). This was the total oscillation from all surfaces on the shuttle. The longitudinal area of a single column was approximately ¼ of the total shuttle projected area. Given this approximation, the oscillation force on a single column was approximately 1.88% of the average force. Such a small oscillation was unlikely to result in concerns of fatigue loads on the shuttle. Fatigue loads cannot be completely excluded without further analysis of the structural design of the buoyancy columns.

CFD PHASE IV - FULL DYNAMIC SIMULATION (Summary of 118-page report in Appendices)

The phase IV CFD analysis simulated the full dynamic motions of the shuttle. The submerged shuttle was permitted full six-degree of freedom motion. This scenario included the shuttle with an ascent velocity inside a water column with a transverse current running from starboard to port. The analysis modeled the catenary lowering lines and included their effects on the shuttle. The shuttle was initially out of equilibrium and allowed to seek an equilibrium position that would balance all hydrodynamic forces against the lowering lines. The total simulation error was 18.4%, which was acceptable for this analysis.

The phase IV results largely validated the concept of the catenary lowering lines. The shuttle showed negligible rotation in pitch and roll, confirming the stability results in previous phases. These were both acceptable and no reason for concern. There was no concern for bending failure in the buoyancy columns due to hydrodynamic pressures. The only outstanding issue was that the catenary concept appeared to create an unstable pendulum motion (from the anchor handling tugs (AHTS)) when exposed to a transverse ocean current. In pendulum motion, the shuttle follows an arc motion path centered on the surface at the AHTS. Without corrective action, this pendulum motion may eventually slowly drive the shuttle to the ocean surface.

The results also showed a suitable mitigation procedure. The pendulum motion was a slow process of several minutes. This should allow the tugs sufficient time to reorient the shuttle so that all ocean currents are in the longitudinal direction. The potential pendulum motion could be mitigated by reorienting the shuttle to ensure it pointed bow heading into the current. It is possible for operators to survey the current profile before shuttle ascent / descent. This could allow operators to anticipate any major heading changes in the shuttle.

The results did illuminate questions about shuttle behavior in combinations of longitudinal and transverse currents. Further analysis is recommended to determine the shuttle dynamics in those scenarios. Analysis methods may incorporate existing CFD data with empirical methods to examine alternative scenarios. CFD analysis is also an acceptable method. Overall, the phase IV CFD analysis revealed a sound concept for the shuttle motions in a full simulated ascent, with the significant result of pendulum motions under certain conditions.

CFD was more appropriate than experimental methods for this analysis. Model testing utilizes small models of the shuttle, but selecting an appropriate model scale is practically impossible when combining multiple physics such as the shuttle. This introduces large uncertainty regarding the interaction of these force components and the resulting behavior of the shuttle. In contrast, CFD eliminates all questions of scaling by modeling all items at full scale.

In addition to scaling concerns, model testing also imposes large practical problems. Most marine testing facilities were built to analyze objects on the water surface. Very few, if any, facilities have tanks with enough water depth to accurately capture the deep water effects. CFD has no such physical limitations. Since all items in CFD are virtual on the computer, the water depth can be as deep as desired.

14.5 DFMECA – Design; Failure Mode, Effects and Criticality Analysis of the Shuttle Design.

A DFMECA and API RP 17N Technology Risk and Readiness Assessment was performed by the contractor group and then subjected to third party review. Each Component of each system was given a Technology Readiness Level (TRL). The TRL numbers range from 0 for an unproven concept with no analysis or testing having been performed, to 7 for a routine field proven system. The system was then assigned a TRL number based on the lowest number from each of its components (Figure 75).

The shuttle's TRL analysis was a natural extension of the API methodology when it was used to review the shuttles structural design and was used to evaluate the required marine operations for deployment and recovery of the shuttle. The SCIU and shuttle equipment analysis was a direct application of the API TRL methodology as applied to equipment or kit. This TRL analysis quickly identified where the maturity of the facility equipment or processes were less mature.

No.	Item	Ref Dwg No.	TRL of Component
2.1	**Deballasting/Vent System**		**6**
2.1.1	Steel Piping	B1228-1-506-001	6
2.1.2	Flanges	B1228-1-506-001	6
2.1.3	Gate Valves	B1228-1-506-001	6
2.1.4	Pressure Relief Valve	B1228-1-506-001	6
2.1.5	Hydraulic Actuator	B1228-1-506-005	6
2.1.6	Compressed Air Connection	B1228-1-506-005	6

Figure 73: Example of Technology Readiness Level (TRL)

Additionally, for each component in the design, a probability of failure and consequence of failure analysis was made. These attributes were then characterized at different levels as shown in the figure below (Figure 76).

Probability:

: Unlikely	: Never heard of in the Oil & Gas Offshore Industry (but still is a possibility).
: Remote	: Heard of in the Oil & Gas Offshore Industry (unlikely but has still happened to others).
: Occasional	: Incident has occurred in Company Operations.
: Frequent	: Incident has occurred several times a year in Company wide Operations.
: Very Frequent	: Happens several times a year at an individual asset

Consequence:

: Minor	: Less than $100,000: Insignificant damage to plant and equipment
: Moderate	: $100,000 - $1,000,000 Limited damage to plant and equipment
: Significant	: $1,000,000 - $10 million: significant damage to local area or essential plant or equipment
: Severe	: $10-100 million Damage extending to several areas/significant impairment of installation / equipment integrity.
: Catastrophic	: >$100 million Severe and extensive damage to plant and/or total asset loss

The two scales together form a risk matrix, as follows:

	A - Unlikely	B - Remote	C - Occasional	D - Frequent	E - Very Frequent
1 - Minor	1A	1B	1C	1D	1E
2 - Moderate	2A	2B	2C	2D	2E
3 - Significant	3A	3B	3C	3D	3E
4 - Severe	4A	4B	4C	4D	4E
5 - Catastrophic	5A	5B	5C	5D	5E

Figure 74: Probability – consequence matrix used in DFMECA

Failure Mode, Effect, Indicators etc. were defined for each system in the spreadsheet excerpt shown below (Figure 77).

No.	Equipment / Function / Requirement	TRL of component	Failure Mode	Effect	Indicators/ Detection	Safeguards
				If it fails, what happens?		Mitigation / Prevention
2.0	Shuttle Systems					
2.1	Deballasting/Vent Syster	6.0	Vent Valves fails to open on sumbergence	ballast tank collapse	Visual Inspection of Valve Status	Visual inspection before deployment

Figure 75: Example of description of failure mode

Consequence and probability are assigned for each component and provided a Risk Color per the matrix shown earlier. Below is an example (Figure 78).

No.	Equipment / Function / Requirement		Criticality		
		Consequence (1-5)	Consequence Description	Probability/ Frequency (A-E)	Risk Category (Color)
2.0	Shuttle Systems				
2.1	Deballasting/Vent Syste	2	Cannot deballast tank upon recovery	B	

Figure 76: Consequence and probability are assigned for each component and provided a Risk Color

The DFMECA results indicate there are no unmanageable risks within the design. A peer level review of the results confirmed the analysis findings.

14.6 Class Society - Approval in Principal.

The design validation process included Class review for Approval in Principal (AiP) for the Shuttle Design. The AIP is an intermediate approval step to provide proof of feasibility to project partners and regulatory bodies. It is a statement of fact that a proposed novel concept or new technology complies with the intent of the most applicable ABS Rules and Guides as well as appropriate industry codes and standards. Below Figure 79 is a copy of the ABS AiP with the road-map / list of submittals necessary to be completed in later phases of the project in order to obtain full Class approval contained within the Appendix 1.

Electronically published by ABS Houston.
Reference T1514786, dated 18-MAY-2016.

OPN: 3670391
Ref. Tasks:
T1514786,T1514787,T1514803,T1514804,T1514805
T1514806,T1514809,T1514820,T1514822,T1515292
T1515320,T1515321,T1515392,T1517281

SUBSEA CHEMICAL SHUTTLE
AIP Review

Alan C. MC Clure Associates, INC. (347650)
2929 Briarpark, Suite 220,
Houston, TX, United States, 77042

Attn: Mr. Miles Williams

We have received your correspondences submitting the documents listed in attachment 1 "Submittal List", for a Recoverable Subsea Chemical Shuttle with multi-Buoyancy column designed to deliver 3000 BBL of several well head chemicals to subsea fields operating in Gulf of Mexico.

The purpose of this review is to investigate the feasibility of the subject conceptual design and identify any major deficiencies that would prove problematic in a full ABS review of the design for classification of the subject Installation.

With the above objective, an independent and unbiased review of the submitted documents with respect to various aspects including Structural, Safety, Foundation, Stability, Electrical, Equipment, Piping and Hydrodynamic & Stationkeeping was performed by ABS OED Houston for compliance in principle with the applicable requirements of the following Rules and Standards:

- ABS Rules for Building and Classing Mobile Offshore Units (MODU Rules), 2015
- ABS Rules for Building and Classing Steel Barges, 2015
- Guidance Notes on Review and Approval of Novel Concepts, June 2003
- Rules for Building and Classing Offshore Installations, 1997

We concluded based on our AIP review that the conceptual engineering as proposed is feasible and the facilities as presented is in principle in compliance with the requirements of the above rules & standards, proven technology and sound engineering practices, provided that the comments in the "ABS Preliminary Review Observations and Comments" as enclosed in attachment 2 are taken into consideration in the next design phase.

The listed comments suggest the methods of calculations, design assumptions, and areas of further engineering that could be addressed during the next design stage.

Please also note that our AIP review at this time in no way precludes any future amendments which may be deemed necessary by the review of detailed engineering for subject Subsea Chemical Shuttle.

An electronic copy of the document, appropriately stamped is available through the ABS Eagle Construct Engineering Manager (O2E), Web Portal.

If you have any comments or questions about our review please do not hesitate to contact us by phone at 281-877-6317 or by email ZhoWang@eagle.org.

Very Truly Yours

Roy Bleiberg
Vice President of Engineering
ABS Americas

By:

Zhongmin Wang
Senior Managing Principal Engineer,
Houston Offshore Engineering Department

Figure 77: ABS Approval in Principal notice

15.0 Marine Operations

During Stage 1 the SMT team led by Helix Canyon Offshore conceptualize a number of different installation scenarios for a safe, reliable, and cost effective methodology and generate operational storyboards and concepts for review and selection of the preferred methodology (See Figure 80). After considerable analysis a dual catenary system 'balancing' the positive buoyancy of the shuttle with the weight of the catenary wire (or rope) and chain was selected (Helix Canyon Offshore, 2015-05-01). Benefits included:

- Catenaries decouple deployment payload from topside handling vessel(s)
- Reduces crane/winch & vessel size requirements
- Provides more vessels of opportunity (VOO) and reduced vessel costs

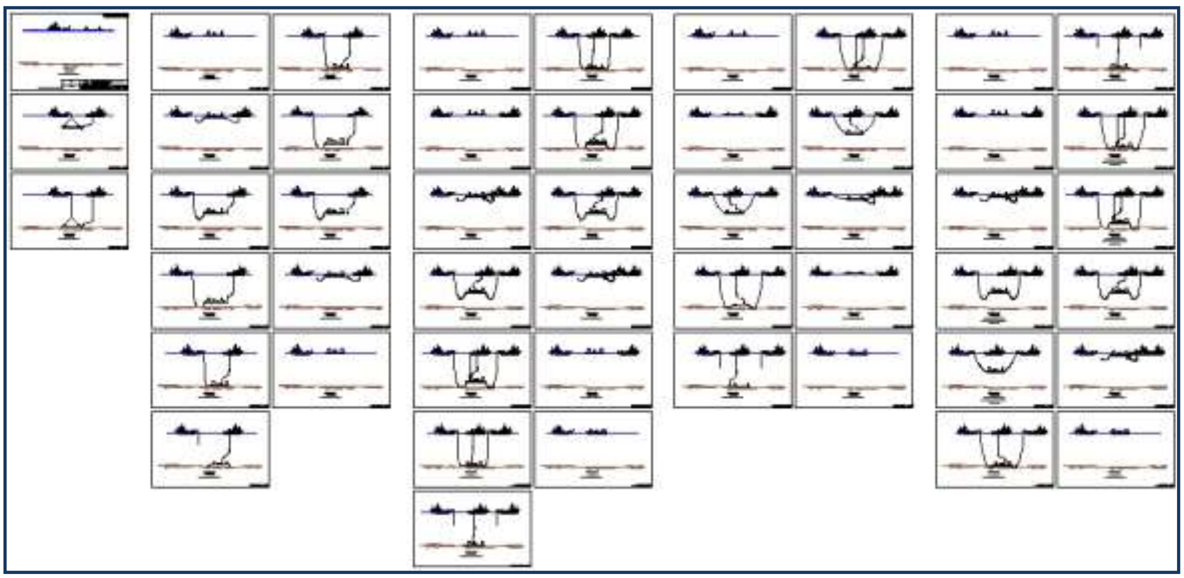


Figure 78: Story-board and conceptual analysis performed in Stage I by Helix Canyon Offshore

15.1 Project requirement

Deliverable: Marine Operational Report and Plan provided to SMT

Description: Canyon's project work is associated with safe shuttle deployment, production, and operations. This includes towing to site, installation on the seafloor, subsea hook-up and commissioning, and recovery to the surface is a cost effective and safe manner. The planned work tasks include the following:

- Participate in a SMT design review workshop for benchmarking the system design, gaps, needs, methods, communications and project expectations for Stage II.
- Interface operational needs and plans with structural and Computational Fluid Dynamic (CFD) analysis for design validation.

- Review and refine with detail all marine operations. Prepare operational outlines and major specifications for support services (vessels, Remote Operated Vehicles (ROVs) and tooling, etc).
- Define the Inspection, maintenance and repair concepts for the shuttle system design. Ensure that the functionality is within the design to support all such operations.
- Develop contingency plans and recovery concepts for all of the appropriate conceivable or identified major failure modes.
- Develop design and operational documentation for final shuttle system configuration.
- Prepare a system availability matrix along with the design team and evaluate its impact on operational costs.
- Develop an operational cost estimate for all the shuttle operations and support services.
- Finalize all marine operation planning and document in outline procedures documentation.
- Update the subsea simulator model with shuttle properties from the CFD, utilizing the services of GRI Simulations (GRI) and Dynamic Systems Analysis (DSA). Then fully simulate and present all marine operations for the final design. Refine the video presentation and operations of the shuttle system to graphically present the shuttle's operation.
- Participate with ACMA in DFEMA, Hazid and HazOps risk reduction meetings.
- Perform project routine reporting, conduct and/or participate in meetings, perform presentations and prepare final project deliverables as requested.

15.2 Project Results

Summary:

There are two methods conceptualized for the chemical storage refilling and maintenance of the various subsystems. These are to:

- Recover the entire shuttle system and return it to port for inspection, maintenance and refilling operations – and potential equipment 'upgrades'. Based on the cost efficiencies associated with SMT's unique procedures for installation and recovery capabilities this is a relatively cost-effective solution. Additionally, it allows for a substantially shorter design life specification than might normally be desired / utilized for a permanent subsea installation.
- Refill the shuttle's flexible storage tank in-situ. This is a complex task and requires a special "nozzle" that throttles the chemical supply pressure to prevent "over-pressurization" of the subsea flexible storage system. A riser, surface ship, surface chemical storage, pump/metering system, and an interface control links are all required.

Superficially, the costs between these two approaches are similar and the choice of the preferred refill – IMR strategy will be field and operator specific. Conceptually, either strategy will work and be available. Further, the sensors, control system, jumpers, and injection unit are all ROV replaceable items if in-situ component maintenance is needed.

This refilling and inspection, maintenance and repair work is broad and an integral part of the complete system. Reports were prepared by Stress Engineering Services to address the long-term in-place operation of the process systems. Two reports, one for the Storage Bladder (SP 5602 Rev B) and another for the Chemical Injection Unit (SP 5601 Rev C), are included in the supporting Stage 1 documentation. Since the concept was being matured, these reports are necessarily generic, with additional detailed OEM designs developed during Stage 2.

Alan McClure Associates prepared a design report (B1228-002-00) on the shuttle's design and included many features supporting the IMR processes. This was accomplished in association with the Marine Operations Analysis and Report (TD-3087-467), prepared by Canyon Offshore and their subcontractor GRI for dynamic subsea installation analysis of the operation.

Transportation, installation & recovery

Design and simulation studies, supplemented with an industry Subject Matter Expert (SME) populated Qualitative Risk Assessment (QRA) from Stage 1 and followed with a Design; Failure Mode, Effects and Criticality Analysis (DFMECA) Stage 2 and have validated the features and functional performance for installing and recovering the subject facilities (~1,000mT). It is also instructive to point out that with minor engineering, similar procedures would be suitable for the cost effective installation and recovery of other large and heavy subsea facilities.

The business driver to mature this technology is the operational cost savings that is achieved by using two anchor handling vessels of opportunity for operational support. Conventional operations would employ heavy lift vessels, with their full spread costs at nearly an order of magnitude higher, plus mobilization and de-mobilization costs and time delays. In addition, the same installation spread is capable of recovering the installed facilities should facility repair, maintenance or refurbishment be required. This feature allows the payload owner to basically design for a much shorter design life and / or to take advantage of technology improvements during the life of the field.

Thus, the potential exists for this deployment technology to create an environment for game changing conditions impacting the architecture, installation and maintenance of major subsea installations as the technology is matured and field utilized. The project has recently completed detailed system design and CFD verification. This significant development project is being monitored and advised by industry representatives through the active representation of operators, service companies and OEMs participating in the project's technical advisory committee and through the significant contribution of data and expertise. Below is a short summary of the operation as the details of the topic are the subject of OTC-26904-MS; A New Subsea Large Load Deployment System

15.3 Concept of Operations

The deployment methodology developed utilizes a two vessel deployment system as shown below in Figure 81. The two primary vessels will likely be anchor handler vessels with stern rollers or vessels with stern A-frames. The Shuttle system will be set up with fixed flotation/buoyancy modules, which remain fixed on the Shuttle. The Shuttle will be configured at about 20-30mT positively buoyant during subsea descent. A pair of catenary chains connected from the primary deployment vessels to the shuttle system will provide additional ballast for submersion of the positively buoyant Shuttle system**.** This will allow for a catenary decoupling of the primary vessels from the Shuttle system mass (including “added-mass” effects). The catenary chain section provides self-compensating shuttle system descent and load control as the Shuttle system’s buoyant properties continually auto balances with the chains’ catenary mass. This allows more flexibility with vessel selection, not requiring large costly vessel(s) for shuttle system deployment. The recovery operations are basically the reverse of deployment.

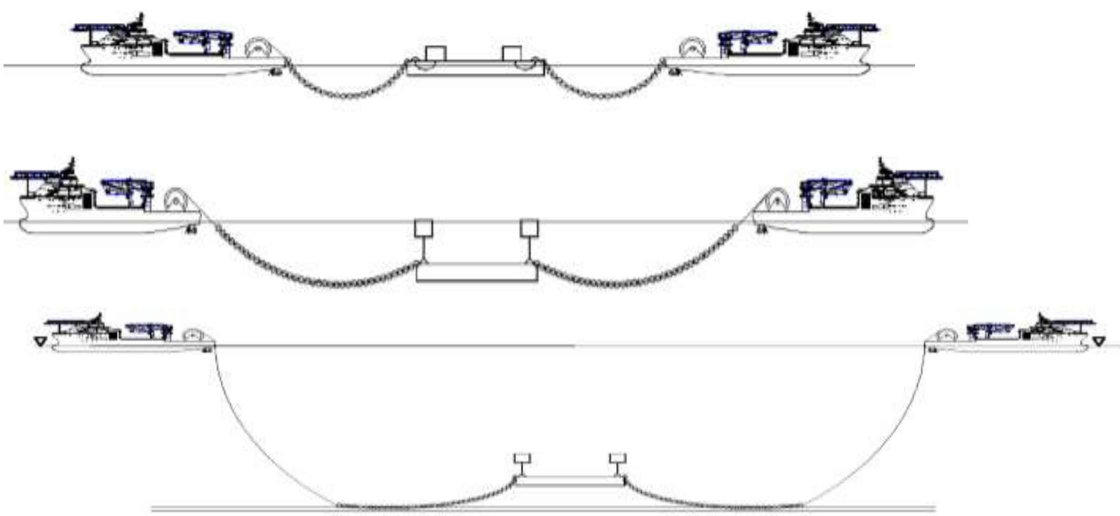


Figure 79: Shuttle deployment utilizing anchor handling vessels of opportunity for operational support

Marine Summary.

Based on single line hoisting loads with the expected mass of the payload shuttle system, a de-coupling method is required. Otherwise, single vessel crane size requirements would become cost prohibitive and vessel of opportunity limiting. De-coupling through the use of a catenary arrangement is ideal for large payload deployment and multiple vessel deployment is ideal for shuttle system positioning during subsea land-out and recovery near subsea infrastructure.

Positively buoyant shuttle system is the most manageable configuration with catenary line loads from the anchor handler vessels. Fixed buoyancy in/on the shuttle system is necessary to help neutralize the shuttle’s steel weight in water, payload weight in water, and ancillary equipment weight in water. Variable buoyancy or ballast in/on the shuttle system is necessary to aid with deployment and recovery of the varying payload specific gravities.

While actual deployment and recovery of the subject Shuttle have not been performed to date, all of the individual marine operations required have been safely performed in numerous other projects. The combination of the four (4) phase CFD study, extensive modeling and simulation analysis utilizing GRi’s

Virtual Dynamics Modules and DSA’s Prometheus DS FEA application[2], and a comprehensive DFMECA, and peer level review of the same give good confidence of marine and economic success. Figures 82 and 83 are screenshots from the simulator.

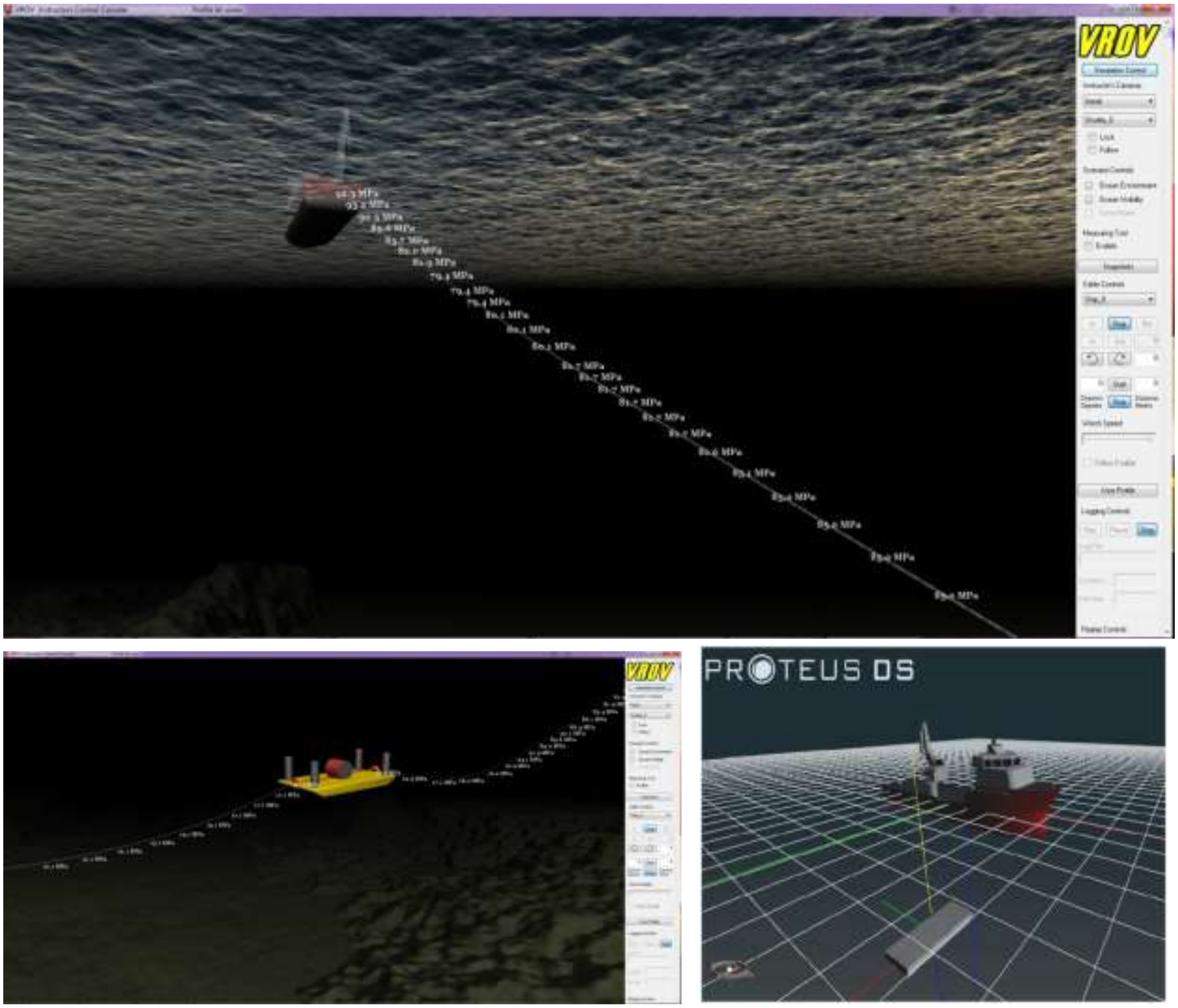


Figure 80: Screen-shots from GRI Simulations Inc. simulations based on DSA project models

[2] The Prometheus DS models are the same engineering analysis tools used to identify concepts and procedures for the transit operations under varying environmental loading conditions. They were validated against ACMA's CFD simulation work over the course of this work.

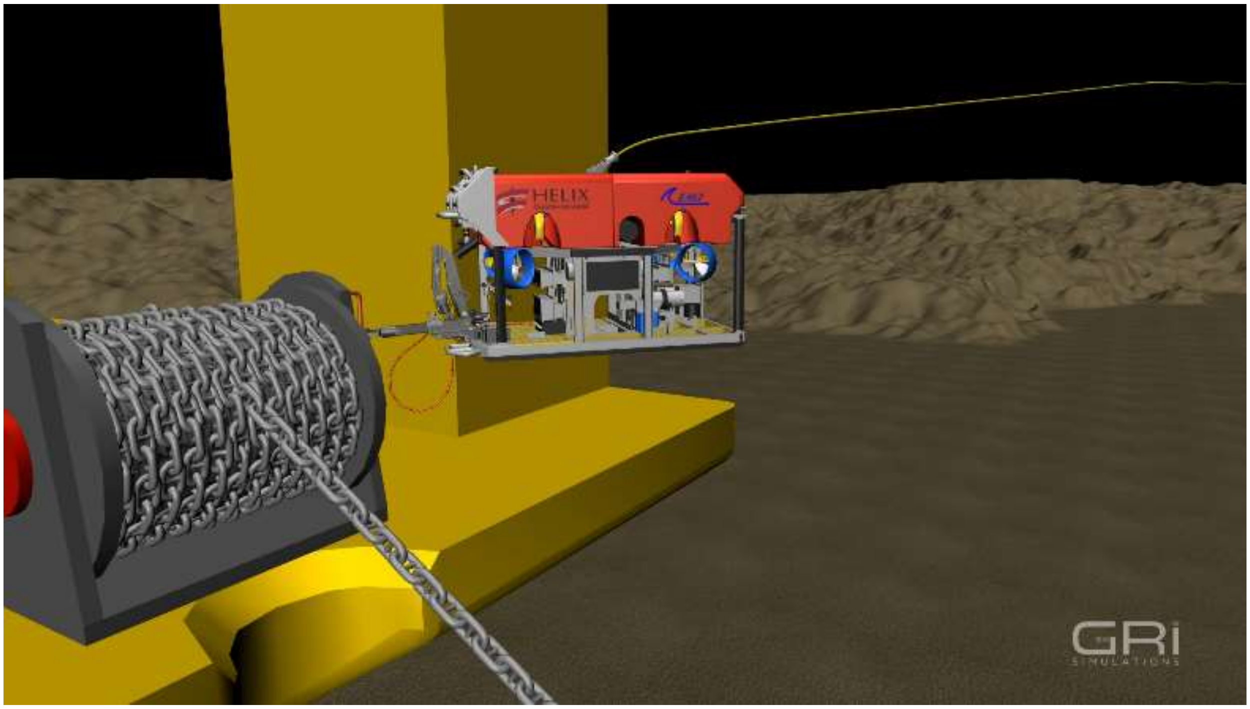


Figure 81: ROV spooling chain on to Shuttle to complete deployment process

Intellectual Property

SMT has extensively used common off the shelf technology in the development of the 3,000 bbl subsea chemical storage and injection system. However, there were gaps that needed to be closed and some of the existing technology identified had to be repurposed and used in novel ways. A summary of SMT IP follows in Table 7:

Title	Date filed	Application #	Status
Patents (United States Patent office)			
Large Volume Subsea Chemical Storage and Metering System	2013, 04-06	13/858,024	Issued #9,079,639 B2
Large Subsea Package Deployment Methods and Devices	2013, 05-05	14/203,635	Issued #9,156,609 B2
A Multi-Vessel Process to Install and Recover Subsea Equipment Packages	2014, 08-27	62 / 042,565	Pending
Underwater Storage Tank	2015, 05-05	62/156,952	Pending
Trade Secrets			
Draws, tables, charts, design and engineering details			

Table 7: Intellectual property status

Conclusions

This RPSEA sponsored project has met all of the original project objectives both technical and financial. It is being completed on-schedule while exceeding the Tech-Transfer requirements for the project as reported earlier in this document.

SMT has two issued US patents and has two pending patent applications for the unique technologies developed through performance of the project. Perhaps the more significant aspect of the project is meeting and exceeding the project's Technical expectations. SMT started development of a 3,000 bbl subsea chemical storage and injection system. In achieving this objective SMT has also:

Enabled Long-distance subsea tie-backs

- The 3000 BBL subsea chemical storage & injection system eliminates the need for a chemical umbilical.
- With the addition of a Subsea pig launcher the need for a 2nd flowline is eliminated.

Both of these changes results in significant cost reductions that will favorably bias economic evaluations for long-distance tieback opportunities.

Shuttle is a Platform for enabling Brownfield IOR

- Shuttle seafloor placement of IOR facilities will enable more Brownfield IOR developments. The Shuttle eliminates the need for expensive existing platform deck space and load or even construction of separate structures that might be required to support IOR operations.

The shuttle developed in this project has a significant side benefit as it causes a step change in operational economics to deploy large and heavy loads to the seafloor. ***SMT believes the Shuttle has potential to significantly change conventional subsea production facilities architecture***.

In today's low product price environment, there is an even greater need to continue development & commercialize this game-changing low-cost solution. For long-distance tie-backs the subsea chemical storage and injection system is enabling technology. Conventional chemical umbilicals are offset limited as they cannot flow the required chemical volumes required for the field's production rates.

In other applications the SMT technology is enhancing simply by being the low-cost alternative. Providing the chemical storage and injection system as an OPEX service has a large enhancing impact on the operator's economics and development flexibility. The OPEX service offers the chance for phased development and improved downside protection for some developments.

The shuttle and chemical storage and injection system is in full compliance with current regulations, rules and requirements. The shuttle as a structure will require periodic inspection over its minimum 10 year design life. The Chemical Storage and Injection system also has a minimum 10 year design life with a minimum in-place operational life of 5 years (confirmed with accelerated bladder material aging tests.) The simple recovery process of the shuttle and its payload enables easy inspection, maintenance and upgrades to be performed as required and convenient. It is this simple installation and recovery feature of the shuttle and payload that enables this important resource to be practically and economically recovered and relocated to other fields.

SMT has completed the system design, verified it and documented it is currently at a TRL 4 (ready for site specific engineering, fabrication and deployment.) This technical state of development is via;

- ✓ Material testing of all bladder materials having any chemical exposure.
- ✓ Detailed modeling both analytically for the system and physically for the contained chemical storage bladders
- ✓ 2 QRAs and two design FMECAs w/ 50+ SME participants – no “un-manageable” risks were identified.
- ✓ 4 US patents were filed, and 2 have been issued
- ✓ Summary report w/ over 2 dozen sub-tasks reported

Potential Next Steps

Throughout the project, the technical personnel have routinely identified work that could be performed to enhance the commercialization of the SMT technologies. Below is some supplemental work that could be performed to accelerate the commercial uptake and build confidence in the technology.

- Perform field study cases (economic analysis). Demonstrating the economics will lead to deployment opportunities.
    - Operators – Support their front-end field development studies
    - Engineering firms (that specialize in front-end field development studies.)

- Additional tech transfer / awareness – to improve industry acceptance of these field development concepts.
    - Conferences – DOT and Pennwell Deepwater conferences
    - Website (to improve functionality)

- Perform economic ‘optimization’ of the system components. Original work identified viable and feasible components but without cost optimization. This work would identify similar function and performance but at optimized costs.
    - Valves / actuators
    - Explore alternative buoyancy

- Marinized pumps have been engineered and final verification of their performance is currently envisioned during extended factory acceptance testing. Some Operators may prefer that a marinized pump be pre-built and tested as a pre-fabrication task to the shuttle construction.

- Adapt/modify the design specifically for well-control operations. This could be dome working with MWCC or similar organizations.

- Build a shuttle deployment demonstration unit and test offshore. This is envisioned being performed in association with cost-share industry partners. The test objective is to demonstrate in the field the ability to install, maneuver and accurately position the shuttle using two AHTS and dual catenary lines. For example, Industry cost share partners may include:
    - An Operator with a possible test site and/or need.
    - MWCC or possibly the
    - DoD

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Attachment 1: Abbreviations and Glossary of project terms

Batch injection	The act of injecting inhibitors continuously for a short time during the normal steady state operation or during shut-in conditions.
Bladder	Flexible fluid containment generally made with plastic or plastic covered fabric which completely surrounds the liquid being held.
Bladder Cell (Compartment)	Smooth surfaced “box” which structurally contains the product and compensation bladders and their surrounding containment fluid.
Bladder, Compensation	Flexible bladder containment within the Bladder Cell and adjacent to the Product Bladder that is filled with sea water and surrounded by the Containment Fluid. This bladder fills out the complete volume and communicates with the outer sea water, expanding and contracting as the Product Cell is emptied or filled or as pressure and temperature changes affect the volume of the other fluids.
Bladder, Product	Flexible bladder containment within the Bladder Cell and surrounded by the Containment Fluid that holds the chemical payload for dispensing into the subsea production system.
Bullheading	The process of injecting inhibitors into the well via the tree during shutdown.
Buoyancy	Force that is the difference between the displacement and the weight of an object. Positive buoyancy is a force upward; negative is a force downward.
Buoyancy Column	Vertical structure rising above the deck of the shuttle.
Containment (or Barrier) Fluid	Liquid, mostly inert, surrounding the Product and Compensation Bladders in the Bladder Cell that provides a buffer in case of any breech of the space or damage to the bladders and prevents the release of any chemicals to the ocean. The Containment Fluid will totally fill the compartment. Mass of the Containment Fluid will remain constant deployment and recovery although there will be some minor change in volume due to temperature and pressure changes. This will be equalized by the expansion or contraction of the Compensation Bladder.
Chemical	Refers to any inhibitors which are injected into the production system to avoid flow assurance issues.
Chemical Delivery System	The combined system that provides delivery of large quantities of well treatment fluids to a deep water subsea production site.

Continuous injection	The act of injecting inhibitors without interruption during the normal steady state operation of the field.
Displacement	The volume or weight of a fluid (as water) displaced by a floating body (as a ship) of equal weight.
Dosing	The act of injecting the required volume of inhibition chemicals at the injection location at pressures above the required injection pressure.
Double Containment	Liquid containment hardware that provides an effective double wall so that any possible release of chemicals would require two concurrent failures (breaches).
Flow Assurance Issues	Various issues like solid deposition, emulsion management, corrosion erosion, etc. that would create hurdles in the normal and economic production of hydrocarbons from the reservoirs.
HOLD	The cargo space of a ship or barge. In SMT's use, it is the internal enclosed space containing and supporting the chemical storage bladder.
Injection location	It is the predetermined location along the production flow-path where the inhibitor is injected.
Injection pressure	The production fluid pressure at the location where the inhibition chemical would be injected. The pressure in the inhibition system at injection location always exceeds the injection pressure.
Jumper flushing	The process of flooding the jumper with Methanol to prevent hydrate formation in and near the jumper.
Production	Refers to production of reservoir fluids such as oil, gas, and water from the reservoir.
Pump	Subsea chemical pump used to boost the inhibitor pressure to deliver the chemical into the flow-path.
Shuttle (barge)	The barge-based vessel that carries the subsea chemical system a shore base to the offshore location, enables lowering to the seabed and also recovery and return to a shore base.
Stability	In general, returning to the original orientation after being disturbed. E.G., a vessel that is stable will roll when it encounters a modest wave and return to upright position.

Subsea boosting	Any combination of pumps located on the sea floor which are used to boost the pressure in subsea production system to enhance the production.
Tie-Back	A subsea production facility that delivers production to a host facility that provides power, and control of the subsea equipment. The subsea facility is a “tie-back” or a satellite installation to the host.
Weight	Force exerted downward by the mass of an object; generally considered at sea level.
Regulations	
33 CFR	Navigation and Navigable Waters regulations in the Code of Federal Regulations.
46 CFR	U.S. Coast Guard enabling regulations in the Code of Federal Regulations.
Regulatory Authorities	
BOEMRE	Bureau of Ocean Energy Management, Regulation and Enforcement
BSEE	Bureau of Safety and Environmental Enforcement – successor to MMS (Minerals Management Service) – charged with enforcing safety and environmental standards for all offshore development projects in U.S. waters.
Abbreviations	
ABS	American Bureau of Shipping
ACMA	Alan C. McClure Associates (Naval architect contractor)
AHT	Anchor Handling Tug
AIP	Approval In Principle
ANSI	American National Standards Institute
API	American Petroleum Institute
AUV	Autonomous Underwater Vehicle
BBL	Barrels of Fluid
BOD	Basis of Design
BOPD or bopd	Barrels of Oil Per Day
BWPD or bwpd	Barrels of Water Per Day
CAN	Canyon (Helix) (Marine operations contractor)

CapEx	Capital Expenditure
CFD	Computational Fluid Dynamics (analysis)
CIU	Chemical Injection Unit
CNG	Compressed Natural Gas
CONOPS	Concept of Operations
COTS	Common Off the Shelf (components)
DC	Design Calculations
DFMECA	Design Failure Modes, Effects and Criticality Analysis
DNV	Det Norske Veritas
DoD	Department of Defense (US)
DOE	Department of Energy (US)
DOT	Department of Transportation (US)
DP	Dynamic Position (vessel)
D/	Downstream of
FEA (Finite Element Analysis)	The process of performing complicated analyses by configuring a numerical model of the system, subdividing it into small portions (elements), evaluating the effect of external or internal conditions on each element and progressively evaluating the effect of each element on adjacent elements. Generally the calculations progress through iterations until the differences between iterations is insignificant and set of final values is determined.
GOM	Gulf of Mexico
GOR	Gas-Oil Ratio
GRI	Simulation & Modeling (Subcontractor)
HazID	Hazard Identification
HazOP	Hazard Operation (analysis)
ICD	Interface Control Document
IOR	Improved Oil Recovery
IRM	Inspection, Maintenance, Repair (process)

ISO	International Standards Organization
LDHI	Low Dosage Hydrate Inhibitor
MDR	Master Document Register
MMscfd	Million standard cubic feet per day
MWCC	Marine Well Containment Corporation
NETL	National Energy Technology Laboratory a part of the DOE (US)
OOIP	Original Oil in Place
OOM	Order of Magnitude
Perf	Near Perforations
psia	Pounds per square inch absolute (a measure of pressure referenced to zero)
psig	Pounds per square inch gauge (a measure of pressure referenced to its environment.)
QRA	Qualitative Risk Assessment
RPSEA	Research Partnership to Secure Energy for America
ROV	Remotely Operated Vehicle
SCSS	Subsea Chemical Storage System
SCIU	Subsea Chemical Injection Unit
SCSSV	Surface Controlled Sub Surface Safety Valve
SME	Subject Matter Expert; persons (versus companies) who are generally recognized by their peers as having expertise in a subject field.
SMT	Safe Marine Transfer, LLC
STB/d	Stock tank barrels per day

TBD	To be Determined
TRC	Technical Readiness Criticality
TRL	Technology Readiness Level
U/	Upstream of
USCG	United States Coast Guard
VOO	Vessel of Opportunity
WPG	Working Project Group; a “RPSEA” term for Subject Matter Experts who have agreed to support the project with their time and expertise

Attachment 2: Master Document Registers, Subcontractor Reports

2.1 Project Reports from Stage II; Summary

1. SCIU - Oceanworks

1.1. Reports (69 files – 87 MB)
- 1.1.1. Engineering Design Report (1133-000-E00001_3 / 101 pages)
- 1.1.2. Flow Calculations Report (1133-000-E10800_00 / 26 pages)
- 1.1.3. Bladder Refill (1133-000-E10900_00 / 16 pages)
- 1.1.4. Budgetary Cost Estimates SCIU (1133-000-E10900_00 / 15 pages)
- 1.1.5. Compliance Matrix (SMT 1133 / xls)
- 1.1.6. CONOPS (1133-000-E107800_02 / 28 pages)
- 1.1.7. DFMECA (1133-000-E00010_2016.04.05 / xls)
- 1.1.8. TRL Report (1133-000-E10500_TRL / xls)

2. Alan C. McClure Associates (ACMA – naval architects)

B1228-1-001 Shuttle Basis of Design r4	6/28/2016 11:05 A...	PDF File	565 KB
B1228-1-002 Shuttle Design Report Rev 3	6/27/2016 4:12 PM	PDF File	8,637 KB
B1228-1-003-02 CFD Phase I	3/9/2016 1:44 PM	PDF File	2,958 KB
B1228-1-004-02 CFD Phase II	3/9/2016 1:52 PM	PDF File	2,085 KB
B1228-1-005-01 CFD Phase III	3/9/2016 2:09 PM	PDF File	1,922 KB
B1228-1-006-01 CFD Phase IV	3/9/2016 2:42 PM	PDF File	4,876 KB
B1228-1-007 Structural Analysis r1	6/6/2016 5:21 PM	PDF File	1,930 KB
B1228-1-008 Shuttle Design FMECA Report Rev 0	3/23/2016 2:34 PM	PDF File	644 KB

3. SCSS - Chemicals

3.1. Baker Hughes
- 3.1.1. MSDS
- 3.1.2. BHI Summary Material Compilation Report (SMT 4)

3.2. Nalco ES LLC
- 3.2.1. MSDS
- 3.2.2. NES LLC material Compatibility Report COREXIT EC9500A

4. Bladder design (9 files - 8 MB)

4.1. Aire https://www.youtube.com/watch?v=O6HORrBWGeY
- 4.1.1. Air_SMT 500 gal Test bladder – engineered design; 2016-03-02
- 4.1.2. Aire bladder – photo 20160411_150505
- 4.1.3. Aire bladder test results_ SKMBT_C22016021509090

4.2. Avon
- 4.2.1. Avon – SMT 1-5 scale bladder 3587102_final

4.2.2. Avon – SMT bladder assembly drawing
4.2.3. Best Practice Guide – Design review
4.2.4. Best Practice Guide – DFMECA
4.2.5. Best Practice Guide – DVPR
4.2.6. Best Practice Guide – NPR

5. Engineered Fabrics
   5.1. Seaman Corp.
      5.1.1. Seaman 8130 XR-5® specs
      5.1.2. Seaman XR-5® Fluid Resistance Guidelines
   5.2. Trelleborg
6. Third party validation - Argen Polymer LLC (5 files – 11MB)
   6.1. Chemical qualification process (labeled SMT-001-7)
   6.2. Material Testing Program
      6.2.1. Argen Reports_SMT-001-1 (100 pages)
      6.2.2. Argen Reports_SMT-001-2 (158 pages)
      6.2.3. Argen Reports_SMT-001-3 (171 pages)
7. Scale Model Test Apparatus
   7.1. SMT Model HOLD and Bladder Objectives and Test Plan
   7.2. SMT test documentation
8. Marine ops - Canyon

TD-3087-447	SMT Stage I Marine Operations Report
TD-3087-453	SMT Stage I Qualitative Risk Assessment
TD-3087-467	SMT Inspection Maintenance Repair Process
TD-3087-468	SMT Component Availability Matrix
TD-3087-474	SMT Qualitative Risk Assessment Pre-Read
TD-3087-484	RPSEA-SMT QRA Spreadsheet, 3-17-15
TD-3087-485	SMT Project Summary Report (and Contract Sub-task Map to Canyon Documents)
TD-3087-486	SMT Economic Analysis Report
TD-3087-487	SMT Mathematical Operational Analysis Report
TD-3087-488	SMT Stage II-III Scope Definition Report
TD-3087-490	SMT Stage II-III Financial Scope Definition
TD-3087-491	SMT Stage II-III Scope Project Schedule
TD-3087-492	RPSEA-SMT QRA Spreadsheet Data
TD-3226-517	SAFE MARINE DEEPWATER RESERVOIR STAGE II REPORT
TD-3226-521	SMT Stage II Project Management Plan Schedule
TD-3226-523	SMT Stage II Canyon CONOPS FMECA
TD-3226-527	SMT Stage II Canyon Interface Control Document
TD-3226-528	SMT Stage II Canyon Compliance Matrix
TD-3226-529	SMT Stage II Canyon QRA Risk Reduction Spreadsheet
TD-3226-538	SMT Stage II Canyon CONOPS FMECA Preread

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2.2 Project Reports from Stage I: Summary

SMT Documentation Matrix					
PMP Deliverable	**SMT**	**ACMA**	**Canyon**	**Stress**	**Others**
5.2 Background Reports					DeepStar 10302 – Subsea storage & Injection
	Dr. Cooper's MetOcean Analysis				Deepstar 10803 & 11803 – Met-ocean data
1.0 Project Management Plan	11121-5302-01-SMT-08-09-2014				
2.0 Technology Status Report	11121-5302-01-SMT-06-14-2014				
3.0 Technology Transfer Plan	11121-5302-01-SMT-06-18-2014				
Stage 1 Report (Task 5.0)					
5.3 Philosophy of Design	11121-5302-01-SMT-10-29-2014				
5.4 Basis of Design	Included with 5.3 Philosophy Report				
5.5 Conceptual Design	11121-5302-01-SMT-01-06-2015	B1228-002-00	TD-3087-447	RP 5401 Rev 3	
5.6 IMR Processes	11121-5302-01-SMT-05-02-2015	B1228-002-00	TD-3087-467	SP 5601 Rev C; SP 5602 Rev B	
5.7 Component Qualification	11121-5302-01-SMT-05-02-2015		TD-3087-468	SP 5701 Rev B; SP 5702 Rev B	
Stage 1 Report (Task 6.0)					
6.1 Qualitative Risk Assessment	11121-5302-01-SMT-05-02-2015	TD-3087-453	TD-3087-453	11121-5302-01-SMT-04-31-2015	
6.2 Critial Component Testing Protocol	11121-5302-01-SMT-05-02-2015			SP 5702 Rev B	
6.3 Verification Tests	11121-5302-01-SMT-05-02-2015				
6.4 Material Screening (Lab Test Analysis)	11121-5302-01-SMT-05-02-2015			RP 6402 Rev B	Baker Chemical Compatibility Testing Data
6.5 Additional Qualification	11121-5302-01-SMT-05-02-2015				
Stage 1 Report (Task 7.0)					
7.1 Detailed Conceptual Design	11121-5302-01-SMT-05-02-2015	B1228-002-00	TD-3087-485	RP 5401 Rev E	
7.2 Hazid & HAZOPs included in Task 6.1	11121-5302-01-SMT-05-02-2015	TD-3087-453	TD-3087-453	11121-5302-01-SMT-04-31-2015	
7.3 System Design Improvement	11121-5302-01-SMT-05-02-2015	B1228-002-00	TD-3087-488	11121-5302-01 SMT 04-27-2015	
7.4 Stage 2 Preparations	11121-5302-01-SMT-05-02-2015				

Table 8: Documentation / Output of Stage I Work

Stress Engineering Services Master Document Register

PN	Doc Type	Sequence No.	Rev	Date Issued yyyy-mmdd	Document Title/Description	Comment
1451130	BD	5401-01	B	2014-1023	Block Diagram Subsea Chemical Injection Unit	Issued for Information
1451130	BD	5401-02	B	2014-1023	Block Diagram Subsea Chemical Injection Unit	Issued for Information
1451130	DR	0001	A	2015-0430	Decision Record Sheet SAFE MARINE TRANSFER, LLC / RPSEA CHEMICAL STORAGE BLADDER CONCEPT DESIGN CONFIGURATION MEHTODOLOGY AND PATH FORWARD	Transmitted with Master Work Book
1451130	DR	0002	B	2015-0430	Decision Record Sheet SAFE MARINE TRANSFER, LLC / RPSEA CHEMICAL STORAGE BLADDER CONCEPT DESIGN CONFIGURATION	Transmitted with
1451130	DS	5501	B	2014-1022	Product Data Sheet: Subsea Chemical Injection Unit MEOH	Issued for Internal Review
1451130	DS	5501	C	2014-1023	Product Data Sheet: Subsea Chemical Injection Unit MEOH	Issued for Information
1451130	DS	5501	D	2014-1119	Product Data Sheet: Subsea Chemical Injection Unit MEOH	Issued for Information
1451130	DS	5501	E	2015-0211	Product Data Sheet: Subsea Chemical Injection Unit MEOH	Issued for Information
1451130	DS	5501	F	2015-0325	Product Data Sheet: Subsea Chemical Injection Unit MEOH	Issued for Information
1451130	DS	5501	G	2015-0407	Product Data Sheet: Subsea Chemical Injection Unit MEOH	Issued for Information
1451130	DS	5502	B	2014-1022	Product Data Sheet SCIU LDHI	Issued for Internal Review
1451130	DS	5502	C	2014-1023	Product Data Sheet SCIU LDHI	Issued for Information
1451130	DS	5502	D	2014-1119	Product Data Sheet SCIU LDHI	Issued for Information
1451130	DS	5502	E	2015-0211	Product Data Sheet SCIU LDHI	Issued for Information

1451130	DS	5502	F	2015-0325	Product Data Sheet SCIU LDHI	Issued for Information
1451130	DS	5502	G	2015-0407	Product Data Sheet Subsea Chemical Injection Unit Low Dosage Hydrate Inhibitor	Issued for Information
1451130	DS	5503	A	Not Started	Product Data Sheet SPCCR Methanol	Not completed. Placeholder for Stage 2
1451130	DS	5504	A	Not Started	Product Data Sheet SPCCR LDHI	Not completed. Placeholder for Stage 2 once bladder vendor is
1451130	DW	5401	A	2014-1023	Concept Sketches T5.4 (DRS) Subsea Pressure Compensate Chemical Reservoir Packaging Options	Issued for Information
1451130	DW	5402	B	2015-0422	PIPING AND INSTRUMENTATION DIAGRAM, SUBSEA CHEMICAL INJECTION UNIT	Issued for Information
1451130	MO	0001	A	2015-0504	Aging/Design and Prototype Development/Computational Analysis	Issued for Internal Review
1451130	PT	1003	B	2015-0430	Stress Presentation; Bladder - Chemistry	Transmitted with Master Work Book
1451130	PT	1004	B	2015-0430	Subsea Chemical Storage and Injection System Stress Presentation	Transmitted with Master Work Book
1451130	RP	1001	A	2014-1023	Project Execution and Communications Guidelines Stage 1	Issued for Internal Review
1451130	RP	1001	B	2014-1023	Project Execution and Communications Guidelines Stage 1	Issued for Information
1451130	RP	1001	D	2015-0407	Project Execution and Communications Guidelines Stage 1	Issued for Information
				11/1/2014		
					Safe Marine Transfer, LLC Stress Engineering Services, Inc.	
					Safe Marine Transfer, LLC Stress Engineering Services, Inc.	
1451130	RP	1003	NA	2015-0430	SMT Subcontractor Monthly Reports (August 2014 - April 2015)	Transmitted with Master Work Book

1451130	RP	5401	A	2014-1023	Report SPCCR Concept Configuration Packaging Evaluation	Issued for Internal Review
1451130	RP	5401	B	2014-1028	Report SPCCR Concept Configuration Packaging Evaluation	Issued for Information
1451130	RP	5401	C	2014-1114	Report SPCCR Concept Configuration Packaging Evaluation	Issued for Information
1451130	RP	5401	D	2014-1119	Report SPCCR Concept Configuration Packaging Evaluation	Issued for Information
1451130	RP	5401	E	2015-0325	Report SPCCR Concept Configuration Packaging Evaluation	Issued for Information
1451130	RP	5501	B	2015-0325	Report Applicable Codes and Standards Review for SCIU and SPCCR	Issued for Information
1451130	RP	5501	C	2015-0430	Report Applicable Codes and Standards Review for SCIU and SPCCR	Issued for Information
1451130	RP	6201	B		Report SPCCR Material Aging Protocol	See 1451130-SS-MO-0001
1451130	RP	6401	B	2015-0325	Bladder Chemical Screening Report – (Subtask 6.4)	Draft Issued for Client Review
1451130	RP	6401	C	2015-0407	Bladder Chemical Screening Report	Issued for Information
1451130	RP	6402	A	2015-0430	Chemical Screening Testing	Issued for Internal Review
1451130	RP	6402	B	2015-0430	Chemical Screening Testing	Issued for Information
1451130	SP	5401	B	2014-1022	Functional Specification Subsea Chemical Injection Unit	Issued for Internal Review
1451130	SP	5401	C	2014-1023	Functional Specification Subsea Chemical Injection Unit	Issued for Information
1451130	SP	5401	D	2014-1119	Functional Specification Subsea Chemical Injection Unit	Issued for Information
1451130	SP	5401	E	2015-0325	Functional Specification Subsea Chemical Injection Unit	Issued for Information
1451130	SP	5401	F	2015-0407	Functional Specification Subsea Chemical Injection Unit	Issued for Information

					Functional Specification SUBSEA PRESSURE COMPENSATED	
					Functional Specification SUBSEA PRESSURE COMPENSATED	
1451130	SP	5402	C	2015-0430	Functional Specification SUBSEA PRESSURE COMPENSATED CHEMICAL RESERVOIR REQUIREMENTS	Issued for Information
1451130	SP	5601	A	2015-0211	Functional Specification: Subsea Chemical Injection Unit Inspection, Maintenance, Repair Requirements	Issued for Information
1451130	SP	5601	B	2015-0325	Functional Specification: Subsea Chemical Injection Unit Inspection, Maintenance, Repair Requirements	Issued for Information
1451130	SP	5601	C	2015-0407	Functional Specification: Subsea Chemical Injection Unit Inspection, Maintenance, Repair Requirements	Issued for Information
1451130	SP	5602	A	2015-0325	Functional Specification: Subsea Pressure Compensated Chemical Reservoir Inspection, Maintenance, Repair Requirements	Issued for Information
1451130	SP	5602	B	2015-0407	Functional Specification: Subsea Pressure Compensated Chemical Reservoir Inspection, Maintenance, Repair Requirements	Issued for Information
1451130	SP	5701	A	2/6/2015 Preliminary	Functional Specification: Subsea Chemical Injection Unit Component Validation and Verification Requirements	Issued for Internal Review
1451130	SP	5701	B	2015-0430	Functional Specification: Subsea Chemical Injection Unit Component Validation and Verification Requirements	Issued for Information
1451130	SP	5702	A	2015-0325	Functional Specification: Subsea Pressure Compensated Chemical Reservoir Component Validation and Verification Requirements	Issued for Information
1451130	SP	5702	B	2015-0430	Functional Specification: Subsea Pressure Compensated Chemical Reservoir Component Validation and Verification Requirements	Issued for Information
1451130	SP	5801	A	2015-0430	Functional Specification SUBSEA PRESSURE COMPENSATED CHEMICAL RESERVOIR INSPECTION/ INSTALLATION MAINTENANCE AND REPAIR REQUIREMENTS	Issued for Information

Helix Canyon Master Document Register

Helix Canyon - MASTER DOCUMENT REGISTER: SUBSEA STORAGE AND TRANSFER RACK, (SSTR)					
	Document Number	Document Title	Document Type	Revision	Revision Date
Design Calculations	**DC-3087-438**	**SMT Deployment Loads Simulation Results**	**Calculations**	**0**	**9/5/2014**
	DC-3087-443	**Flotation and Buoyancy Calculator**	**Calculations**	**2**	**9/30/2014**
	DC-3087-469	**DSA Report - Ops Analysis**	**Calculations**	**B**	**4/20/2015**
Economic Calculations	**EC-3087-441**	**SMT Economic Comparison Matrix**	**Calculations**	**3**	**2/18/2015**
Engineering Reports	**ER-3087-440**	**RPSEA - SMT Canyon Engineering Progress Report (monthly report)**	**Presentation**	**10b**	**4/13/2015**
	ER-3087-449	**SMT Canyon WPG Committee Presentation**	**Presentation**	**5**	**2/18/2015**
Master Document Register	**MDR-3087-472**	**RPSEA SMT Document Register**	**Register**	**1**	**4/22/2015**
Minutes Of Meetings	**MOM-3087-178**	**RPSEA-SMT Minutes of Meeting, 1-26-2015**	**Meeting Minutes**	**A**	**3/10/2015**
	MOM-3087-179	**RPSEA-SMT Minutes of Meeting, 2-04-2015**	**Meeting Minutes**	**A**	**3/10/2015**
	MOM-3087-180	**RPSEA-SMT Minutes of Meeting, 2-19-2015**	**Meeting Minutes**	**A**	**3/10/2015**
	MOM-3087-181	**RPSEA-SMT Minutes of Meeting POST MEETING, 2-19-2015**	**Meeting**	**A**	**3/10/2015**
	MOM-3087-482	**RPSEA-SMT Minutes of Meeting, 2-12-2015**	**Minutes Meeting**	**A**	[illegible]
	MOM-3087-483	**RPSEA-SMT Minutes of Meeting, 3-17-2015**	**Meeting Minutes**	**A**	**3/17/2015**
Technical Document	**TD-3087-447**	**RPSEA - SMT Stage I Marine Operations Report**	**Report**	**5**	**4/22/2015**
	TD-3087-453	**RPSEA - SMT Stage I Qualitative Risk Assessment**	**Assessment**	**0**	**4/22/2015**
	TD-3087-467	**RPSEA - SMT Inspection Maintenance Repair Process**	**Report**	**0**	**4/22/2015**
	TD-3087-468	**RPSEA - SMT Component Availability Matrix**	**Report**	**0**	**4/22/2015**
	TD-3087-474	**RPSEA - SMT Qualitative Risk Assessment Pre-Read**	**Report**	**1**	**4/22/2015**
	TD-3087-484	**RPSEA-SMT QRA Spreadsheet, 3-17-15**	**Spreadsheet**	**0**	**3/25/2015**
	TD-3087-485	**RPSEA-SMT Project Summary Report (and Contract Sub-task Map to Canyon Documents)**	**Report**	**0**	**4/22/2015**
	TD-3087-486	**RPSEA-SMT Economic Analysis Report**	**Report**	[illegible]	[illegible]
	TD-3087-487	**RPSEA-SMT Mathematical Analysis Report**	**Report**	**0**	**4/22/2015**
	TD-3087-488	**RPSEA-SMT Stage II-III Scope Definition Report**	**Report**	**0**	**4/22/2015**
	TD-3087-490	**RPSEA-SMT Stage II-III Financial Scope Definition**	**Report**	**0**	**4/22/2015**
	TD-3087-491	**RPSEA-SMT Stage II-III Scope Project Schedule**	**Schedule**	**0**	**4/17/2015**
	TD-3087-492	**RPSEA-SMT QRA Spreadsheet Data**	**Spreadsheet**	**0**	**4/20/2015**
Vendor Documents	**N/A**	**SMT Concept Selection Report**	**Report**	**N/A**	**9/30/2014**
	N/A	**SMT Project Selection Report**	**Report**	**N/A**	**9/30/2014**
	N/A	**DSA-GRI-SMTSB Assessment**	**Assessment**	**C**	**10/29/2014**
	N/A	**DSA-GRI-SMTSB Benchmark Depth Analysis**	**Report**	**B**	**3/11/2015**
	N/A	**RA Spreadsheet 3-17-2015 rough data**	**Excel data**	**N/A**	**3/17/2015**
	N/A	**SMT's QRA Spreadsheet 3-18-2015 for review rev. B**	**Excel data**	**N/A**	**3/20/2015**
	N/A	**SMT's QRA Spreadsheet 3-18-2015 populated and colored rev. C**	**Excel data**	**N/A**	**3/24/2015**
	N/A	**Company 1 QRA Spreadsheet**	**Excel data**	**N/A**	**4/8/2015**

DeepStar and Background Reports

DeepStar Feasibility Reports	2014, 07-25	10302 – Subsea storage & Injection 10803 & 11803 – Met-ocean data
DeepStar Met-Ocean report	2014, 09-27	On RPSEA SharePoint site (Provided Dr. Cortis Cooper; Chevron Fellow)
Fugro Geotechnical Report	2014, 10-17	Reviewed extensive database and developed seafloor geotechnical information presented in BOD.
Baker Hughes Chemicals	2014, 11-21	Provided a database of material compatibility with Methanol and LDHI.
Operator survey results for design basis input (SMT report)	2014, 10-13	9 operators provided production chemical usage and rates for BOD development
BSSE input and review	2014, 11-21	Face to face review and discussion with regulators. BSEE stated they saw no 'show-stoppers' and were excited with the SMT concept as an improvement over current technology solutions.
UH literature & technology review	2014, 11-21	This extensive search identified patents, papers, presentations and background information for the use of the project.

Table 9: Reports and other information contributed to the SMT Project

SMT - Philosophy of Design Report

SMT report No. 11121-5302-01-SMT-10-29-2014, (section 5.4 of BoD report.)

SMT - Basis of Design

SMT Document No. 11121-5302-01-SMT-10-29-2014

SMT - Conceptual Design

SMT Document No. 11121-5302-01-SMT-01-06-2015

Attachment 3: Tech Transfer, Routine Reporting & Subject Matter Expert (SME) Contributions

3.1 Activities from Stage II: Summary

SMT participated in a number of technology transfer activities as summarized in the table below.

Technology Transfer:

RPSEA 'Best-of' conference	2016, 08-30	RPSEA + public
Final report-out	2016, 07-13&14	RPSEA + invities
OTC	2016, 05-04	NETL & RPSEA booth presentation
OTC	2016, 05-04	Published and presented technical paper #26966
OTC	2016, 05-03	Published and presented technical paper #26904
OTC	2016, 05-02	Presented technical overview
Website	2016, 05-01	Website goes live www.SafeMarinetransfer.com
Houston Technology Center	2016, 04-05	Technical overview presentation
DOT 2016	2016, 03-24	Submitted technical abstract for Oct 2016 event
RPSEA WPG – SCIU & SCSS DFMECA	2016, 02-16	29 participants – including BSSE
RPSEA WPG – Shuttle & Marine DFMECA	2016, 01-28	26 participants – including BSSE
RPSEA TAC meeting	2016, 01-21	SMT report-out
World Oil	2015, 12-01	Published editorial article
Rice University	2015, 09-17	SMT, short presentation
Helix Newsletter	2015, 09-18	Companywide publication
RPSEA; WPG and SME input to PMP	2015, 06-30	RPSEA + 11 SME
RPSEA TAC meeting	2015, 06-10	SMT Report-out
OTC	2015, 05-06	NETL & RPSEA booth presentation

Table 10: Technology transfer activities, Stage II

Throughout the course of the project SMT obtained input from stakeholders and technology suppliers. The table below lists the various meeting which were held, supplementing numerous web searches and telephone discussions.

Project review and SME input meetings:

Meeting	Date	Participants / comment
Buoyancy	2016, 05-20	SMT + Trelleborg
Re-fill (risers)	2016, 05-18	SMT + Airborne
Buoyancy	2016, 05-18	SMT + Balmoral
Approval in Principal	2016, 04-19	SMT + RPSEA + Canyon + ACMA + ABS
Buoyancy	2016, 04-07	SMT + RPSEA + Magma
Marine ops review	2016, 03-31	SMT + Canyon + DSA + GRI
Field development – case studies	2016, 03-01	SMT + FMC
CFD review	2016, 02-25	SMT + RPSEA + ACMA
AUV interface	2016, 02-11	SMT + Canyon + Saab
Immersion testing	2015, 12-29	SMT + RPSEA + Argen
Bladder fabrication / material	2015, 12-22	SMT + Aire + Seanman Corp

Bladder fabrication	2015, 12-10	SMT + Avon
Shuttle DFMECA review	2015, 12-09	SMT + RPSEA + Canyon + ACMA + Oceanwoks
Bladder fabrication	2015, 12-08	SMT + AIRE
Overall economics	2015, 10-01	SMT + Avon
Shuttle	2015, 09-25	SMT + Atkins / HOE
Bladder fabrication	2015, 09-22	SMT + ATL
Stage II Project KO mtg	2015, 08-05	SMT + RPSEA + OW + ACMA + CAN
Chemical testing	2015, 08-04	SMT + Argen
Chemical testing	2015, 08-04	SMT + Element
Shuttle	2015, 07-29	SMT + RPSEA + ACMA
Chemical storage & measurement	2015, 07-15	SMT + Battelle
Marine ops	2015, 06-26	SMT + RPSEA + Canyon
Chemical	2015, 06-11	SMT + RPSEA + BHI
Shuttle / Marine	2015, 06-05	SMT + RPSEA + Exmar
Process	2015, 06-04	SMT + RPSEA + Oceanworks
Bladder material & construction	2015, 05-27	SMT + RPSEA +Trelleborg
Shuttle design	2015,05-26	SMT + RPSEA + Zentech
Process	2015, 05-21	SMT + RPSEA + Genesis
Chemical storage & measurement	2015, 05-20	SMT + Battelle
Bladder material & construction	2015, 05-19	SMT + Trelleborg
Chemical data	2015,05-18	SMT + BHI; input on chemicals
Process	2015, 05-11	SMT + OceanWorks + RPSEA, project coordination

Table 11: Technology and stakeholder input meetings

3.2 Activities from Stage I: Summary

Technology Transfer:

World Oil	2014, 12-01	Published editorial article
Rice University	2014, 09-11	Presented
Video output of simulation model	2014, 08-31	Built and distributed (available on U-Tube)
RPSEA UDW Conference	2014, 09-03	Presented, ~ 150 participants
Deep Ocean, Deep Space Technologies	2015, 04-07	Participated
Project Design meeting	2014, 07-22	RPSEA + 11 SME
Project Design meeting	2014, 08-20	RPSEA + 13 SME

Table 12: Technology transfer activities, Stage 1

Project review and SME input meetings:

Meeting	**Date**	**Participants / comment**
RPSEA project KO mtg	2014, 05-27	RPSEA & SMT
Project Design mtg	2014, 07-22	RPSEA + 11 SME
Project Design mtg	2014, 08-20	RPSEA + 13 SME
RPSEA UDW conference	2014, 09-03	~ 150 participants
RPSEA TAC mtg	2014, 11-05	RPSEA + 25 SME
RPSEA Champion (Total) mtg	2014, 11-18	RPSEA Champion + SMT & subs

Bureau of Safety & Environmental Enforcement – BSSE (DoI) mtg	2014, 10-23 2014, 11-21	BSEE + SMT BSEE + RPSEA + NETL + SMT & subs
Southwest Research Institute (SwRI)	2015, 01-12	SwRI provided 3rd party validation of the SMT concept.
RPSEA Subsea Systems TAC mtg, SMT review	2015, 01-20	MoM on SharePoint; SMT presentation & input from RPSEA TAC
SMT + GE technical mtg	2015, 01-20	Project input
RPSEA WPG mtg	2015, 01-22	MoM on SharePoint ; WPG + select oil companies, input to SMT
RPSEA WPG mtg	2015, 01-26	MoM on SharePoint ; RPSEA WPG + SMT + subs presentation
RPSEA WPG mtg	various	MoM on SharePoint; several 1 on 1 SMT + Oil company meetings
NETL mtg	2015, 01-30	NETL + SMT
Chevron / DeepStar mtg	2015, 02-02	Project input
RPSEA mtg	2015, 02-04	Project input
BHI mtg	2015, 02-11	Project input
RPSEA WPG mtg	2015, 02-19	MoM on SharePoint, RPSEA WPG + SMT + subs present
RPSEA WPG QRA (Shuttle & Marine ops) review mtg	2015, 03-17	MoM on SharePoint; 25 SME participants; full review with no unmanageable risk identified and recommendation to proceed
RPSEA WPG QRA (Storage & SCIU) review mtg	2015, 04-15	MoM on SharePoint; 26 SME participants; full review with no unmanageable risk identified and recommendation to proceed

Table 13: Technology development and stakeholder input meetings, Stage I

3.3 Deliverables from Stage II: Summary

Reports and documents:

Document No.	Revision	Title	Issue Date	Comments
11121-5302-01-SMT-07-10-2016		Stage II Report (Final)	2016, 07-10	Following RPSEA review and comments, the draft report will be revised and issued as final.
11121-5302-01-SMT-07-15-2016		Stage II Final Presentation Materials		Uploaded to RPSEA SharePoint site.
11121-5302-01-SMT-06-05-2016		Stage II Report (Draft) including - Onshore Subassembly Testing (Scale Model Bladder Test) - Prototype Design and Fabrication Summary (CFD & SCIU & Shuttle Design)	06-05-2016	
		Monthly Status Reports & Interim Requests (Task 10)		
2016-08		Aug 2016 Monthly report		
2016-07		Jul 2016 Monthly Report		

2016-06		Jun 2016 Monthly Report	2016, 07-12	
2016-05		May 2016 Monthly Report	2016, 06-10	
2016-04		Apl 2016 Monthly Report	2016, 05-12	
2016-03		Mar 2016 Monthly Report	2016, 04-10	
2016-02		Feb 2016 Monthly Report	2016. 03-09	
2016-01		Jan 2015 Monthly Report	2016, 02-10	
2015-12		Dec 2015 Monthly Report	2016, 01-09	
2015-11		Nov 2015 Monthly Report	2015, 12-13	
2015-10		October 2015 Monthly Report	2015, 11-09	
2015-09		September 2015 Monthly Report	2015, 10-12	
2015-08		August 2015 Monthly Report	2015, 09-13	
2015-07		July 2015 Monthly Report	2015, 08-13	
2015-06		June 2015 Monthly Report	2015, 07-29	
2015-05		May 2015 Monthly Report	2015, 06-25	
11121-5302-01-SMT-07 -18-2015		Project Management Plan (Task 1) – FINAL	2015, 07-18	
11121-5302-01-SMT-05-09-2015		Project Management Plan (Task 1) – Draft	2015, 05-09	

Table 14: RPSEA Stage II Deliverables

3.4 Deliverables from Stage I: Summary

Reports and documents:

Document No.	Revision	Title	Issue Date	Comments
11121-5302-01-SMT-08-09-2014	Rev A	Project Management Plan (Task 1) – Draft and Final	6/25/2014	Final Revision 8-9-2014
11121-5302-01-SMT-06-14-2014	Rev A	Technology Status Report (Task 2)	6/14/2014	
11121-5302-01-SMT-06-18-2014	Rev A	Technology Transfer Plan (Task 3)	6/18/2014	
		Monthly Status Reports & Interim Requests (Task 4)		
2014-05		May 2014 Monthly Report	6/14/2014	
2014-06		June 2014 Monthly Report	7/4/2014	
2014-07		July 2014 Monthly Report	8/10/2014	
2014-08	Rev 1	August 2014 Monthly Report	9/9/2014	
2014-09		September 2014 Monthly Report	10/19/2014	
2014-10		October 2014 Monthly Report	11/15/2014	
2014-11		November 2014 Monthly Report	12/14/2014	
2014-12		December 2014 Monthly Report	1/22/2015	

2015-01		January 2015 Monthly Report	2/9/2015	
2015-02		February 2015 Monthly Report	3/20/2015	
2015-03		March 2015 Monthly Report	4/14/2015	
11121-5302-01-SMT-20140704		One Page Project Summary	7/4/2014	NETL Request
11121-5302-01-SMT-12-22-2014		End of Year Project Status	12/22/2014	NETL Request
11121-5302-01-SMT-04-10-2015		SMT Project Headliners	4/10/2015	Announcement of New Project Champion
		DeepStar Report 10302 – Subsea Storage and Injection Report	7/25/2014	DeepStar Background Report
		DeepStar Reports 10803 & 11803	7/25/2014	DeepStar MetOcean Reports
11121-5302-01-SMT-10-29-2014	Rev 4	Development Philosophy (Task Report 5.3) and Basis of Design (Task Report 5.4)	10/29/2014	Issued as developed. These are components of the Stage 1 Final Report.
11121-5302-01-SMT-01-06-2015		Conceptual Design Report (Task Report 5.5)	1/6/2015	Establishes the system concept and many trade-off evaluations.
11121-5302-01-SMT-05-02-2015		Stage 1 Report (Draft)	5/8/2015	This draft Report is supported by subcontractor reports identified in Table 3 as well as the 2 QRA; - pre-reads - daylong workshops - summary reports
11121-5302-01-SMT-05-10-2015		Stage 1 Report (Final)	5/09/2015	Following RPSEA review and comments, the draft report will be revised and issued as final.
11121-5302-01-SMT-05-09-2015		Stage 1 Final Presentation Materials	5/9/2015	Uploaded to RPSEA SharePoint site.

Table 15: RPSEA Stage I Deliverables

Appendix 1: Shuttle System - Design Details

The below data, reports and information were developed during the course of the project and are proprietary and being held confidential. Upon request from qualified parties, some of the information may be released by SMT under a suitable NDA.

9. ABS AIP (23 files - 42 MB)
    9.1. ABS AiP letter
    9.2. ACMA response to ABS letter
    9.3. Drawings provided to ABS (21 files -.pdf)

10. Canyon Transfer (24 files – 504 MB)
    10.1. Phase IV CFD Animations (7 files – 491 MB - .ogv)
    10.2. Phase IV Data (9 files – 1.4 MB – .xls)
    10.3. CFD Reports (4 – 10 MB – pdf0)
    10.4. CFD Phase I drag Coefficients R0 (1 file 260KB - .xls)
    10.5. SMT Shuttle Geometry (3 files – 3MB - .stp & .igs)

11. Drawings – final (13 files – 4.5 MB - .pdf)

B1228-1-070-001 General Arrangement Rev 0	4/6/2016 4:32 PM	PDF File	268 KB
B1228-1-070-002 Tank Plan Rev 0	4/6/2016 4:32 PM	PDF File	194 KB
B1228-1-100-001 Hull Structural Arrangement Rev 0	4/6/2016 4:32 PM	PDF File	1,080 KB
B1228-1-100-002 Buoyancy Cylinder Support Structure Rev 0	4/6/2016 4:32 PM	PDF File	543 KB
B1228-1-100-003 Bolted Watertight Hatches Rev 0	4/6/2016 4:33 PM	PDF File	351 KB
B1228-1-100-004 Jettisonable Solid Ballast Blocks Rev 0	4/7/2016 10:21 AM	PDF File	807 KB
B1228-1-500-001 Ballast System P&ID Rev 0	4/6/2016 4:33 PM	PDF File	214 KB
B1228-1-500-002 De-ballasting System P&ID Rev 0	4/6/2016 4:33 PM	PDF File	142 KB
B1228-1-500-003 Shuttle Cargo Piping Rev 0	4/7/2016 10:24 AM	PDF File	164 KB
B1228-1-500-004 Water Jetting System P&ID Rev 0	4/6/2016 4:33 PM	PDF File	226 KB
B1228-1-506-001 Tank Vents P&ID Rev 0	4/6/2016 4:33 PM	PDF File	133 KB
B1228-1-554-001 Ctrl, Alarm, Monitoring System Rev 1	4/6/2016 4:32 PM	PDF File	146 KB
B1228-1-554-002 Valve Control System P&ID Rev 0	4/6/2016 4:33 PM	PDF File	287 KB

12. Phase IV CFD Animations (7 files – 491 MB - .ogv)

13. Report (9 files – 50 MB)

DFMECA ACMA R2	2/23/2016 5:19 PM	Microsoft Excel W...	270 KB
B1228-1-001 Shuttle Basis of Design r4	6/28/2016 11:05 A...	PDF File	565 KB
B1228-1-002 Shuttle Design Report Rev 3	6/27/2016 4:12 PM	PDF File	8,637 KB
B1228-1-003-02 CFD Phase I	3/9/2016 1:44 PM	PDF File	2,958 KB
B1228-1-004-02 CFD Phase II	3/9/2016 1:52 PM	PDF File	2,085 KB
B1228-1-005-01 CFD Phase III	3/9/2016 2:09 PM	PDF File	1,922 KB
B1228-1-006-01 CFD Phase IV	3/9/2016 2:42 PM	PDF File	4,876 KB
B1228-1-007 Structural Analysis r1	6/6/2016 5:21 PM	PDF File	1,930 KB
B1228-1-008 Shuttle Design FMECA Report Rev 0	3/23/2016 2:34 PM	PDF File	644 KB

14. Met-ocean work
    - 14.1. DeepStar reports
    - 14.2. DeepStar data
    - 14.3. Dr. Cortis Cooper report

15. Foundation / seafloor
    - 15.1. Fugro reports
    - 15.2. Fugro summary charts

16. Buoyancy
    - 16.1. Hexagon - Lincoln detail
    - 16.2. Inspection manual
    - 16.3. Canadian approvals
    - 16.4. ABS requirements

Appendix 2: Subsea Chemical Injection Unit (SCIU) - Design Details

The below data, reports and information were developed during the course of the project and are proprietary and being held confidential. Upon request from qualified parties, some of the information may be released by SMT under a suitable NDA.

1. Oceanworks

   1.1. Reports (69 files – 87 MB)
      1.1.1. Engineering Design Report (1133-000-E00001_3 / 101 pages)
      1.1.2. Flow Calculations Report (1133-000-E10800_00 / 26 pages)
      1.1.3. Bladder Refill (1133-000-E10900_00 / 16 pages)
      1.1.4. Budgetary Cost Estimates SCIU (1133-000-E10900_00 / 15 pages)
      1.1.5. Compliance Matrix (SMT 1133 / xls)
      1.1.6. CONOPS (1133-000-E107800_02 / 28 pages)
      1.1.7. DFMECA (1133-000-E00010_2016.04.05 / xls)
      1.1.8. TRL Report (1133-000-E10500_TRL / xls)

   1.2. Data (30 files - 53 MB)
      1.2.1. Bill of Materials (1133-000-E10100 / xls)
      1.2.2. Data Sheets

   1.3. Drawings – final (13 files – 4.5 MB - .pdf)
      1.3.1. LDHI SCIU (1133-120-A60000_2)
      1.3.2. MeOH SCIU (1133-120-A50000_2)
      1.3.3. Interface Control Diagram (1133-000-E00040_02)
      1.3.4. Electrical Schematics (1133-600-S10000_A_2016.04.11)
      1.3.5. Hydraulic Schematic (1133-000-E10000_15)

2. DeepStar Report 10302 (1 file – 3 MB)

3. Inflection Consulting (7 files – 5 MB)

   3.1. Contamination Sensor and Storage Volume Measurement Technology Overview Report
   3.2. Data and support

Appendix 3: Subsea Chemical Storage System (SCSS) - Design Details

The below data, reports and information were developed during the course of the project and are proprietary and being held confidential. Upon request from qualified parties, some of the information may be released by SMT under a suitable NDA.

1. Chemicals (9 files – 1.4 MB)
   1.1. Baker Hughes
      1.1.1. MSDS
      1.1.2. BHI Summary Material Compilation Report (SMT 4)
   1.2. Nalco ES LLC
      1.2.1. MSDS
      1.2.2. NES LLC material Compatibility Report COREXIT EC9500A

2. Bladder design (9 files - 8 MB)
   2.1. Aire https://www.youtube.com/watch?v=O6HORrBWGeY
      2.1.1. Air_SMT 500 gal Test bladder – engineered design; 2016-03-02
      2.1.2. Aire bladder – photo 20160411_150505
      2.1.3. Aire bladder test results_ SKMBT_C22016021509090
   2.2. Avon
      2.2.1. Avon – SMT 1-5 scale bladder 3587102_final
      2.2.2. Avon – SMT bladder assembly drawing
      2.2.3. Best Practice Guide – Design review
      2.2.4. Best Practice Guide – DFMECA
      2.2.5. Best Practice Guide – DVPR
      2.2.6. Best Practice Guide – NPR

3. Engineered Fabrics
   3.1. Seaman Corp.
      3.1.1. Seaman 8130 XR-5® specs
      3.1.2. Seaman XR-5® Fluid Resistance Guidelines
   3.2. Trelleborg

4. Third party validation - Argen Polymer LLC (5 files – 11MB)
   4.1. Chemical qualification process (labeled SMT-001-7)
   4.2. Material Testing Program
      4.2.1. Argen Reports_SMT-001-1 (100 pages)
      4.2.2. Argen Reports_SMT-001-2 (158 pages)
      4.2.3. Argen Reports_SMT-001-3 (171 pages)

5. Scale model Test Apparatus
   5.1. SMT Model HOLD and Bladder Objectives and Test Plan
   5.2. SMT Test Documentation and Results

Appendix 4: Marine Operations and Operational Simulations

MASTER DOCUMENT REGISTER: SUBSEA STORAGE AND TRANSFER RACK, (SSTR)					
	Document Number	**Document Title**	**Document Type**	**Revision**	**Revision/Issue Date**
Design Calculations	DC-3087-438	SMT Deployment Loads Simulation Results	Calculations	1	7/7/2016
	DC-3087-443	Flotation and Buoyancy Calculator	Calculations	3	7/7/2016
	DC-3087-469	DSA Report - Ops Analysis	Calculations	1	7/7/2016
Economic Calculations	EC-3087-441	SMT Economic Comparison Matrix	Calculations	4	7/7/2016
	EC-3226-522	SMT Stage II Economic Comparison Matrix	Calculations	0	6/3/2016
Engineering Reports	ER-3087-440	RPSEA - SMT Canyon Engineering Progress Report (Stage I monthly report)	Presentation	10b	4/13/2015
	ER-3087-449	SMT Canyon WPG Committee Presentation	Presentation	7	9/28/2015
Master Document Register	MDR-3087-472	RPSEA SMT Document Register (Stage I)	Register	1	5/4/2015
	MDR-3226-516	Safe Marine Deepwater Stage II Document Register	Register	this document	this document
Minutes Of Meetings	MOM-3087-178	RPSEA-SMT Minutes of Meeting, 1-26-2015	Meeting Minutes	A	3/10/2015
	MOM-3087-179	RPSEA-SMT Minutes of Meeting, 2-04-2015	Meeting Minutes	A	3/10/2015
	MOM-3087-180	RPSEA-SMT Minutes of Meeting, 2-19-2015	Meeting Minutes	A	3/10/2015

	MOM-3087-181	RPSEA-SMT Minutes of Meeting POST MEETING, 2-19-2015	Meeting Minutes	A	3/10/2015
	MOM-3087-482	RPSEA-SMT Minutes of Meeting, 2-12-2015	Meeting Minutes	A	3/12/2015
	MOM-3087-483	RPSEA-SMT Minutes of Meeting, 3-17-2015	Meeting Minutes	A	3/17/2015
Technical Document	TD-3087-447	SMT Stage I Marine Operations Report	Report	7	7/7/2016
	TD-3087-453	SMT Stage I Qualitative Risk Assessment	Assessment	2	7/7/2016
	TD-3087-467	SMT Inspection Maintenance Repair Process	Report	2	7/7/2016
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	TD-3087-485	SMT Project Summary Report (and Contract Sub-task Map to Canyon Documents)	Report	2	7/7/2016
	TD-3087-486	SMT Economic Analysis Report	Report	2	7/7/2016
	TD-3087-487	SMT Mathematical Operational Analysis Report	Report	2	7/7/2016
	TD-3087-488	SMT Stage II-III Scope Definition Report	Report	4	7/7/2016
	TD-3087-490	SMT Stage II-III Financial Scope Definition	Report	4	7/7/2016
	TD-3087-491	SMT Stage II-III Scope Project Schedule	Schedule	3	6/25/2015
	TD-3087-492	RPSEA-SMT QRA Spreadsheet Data	Spreadsheet	1	7/7/2016
	TD-3226-517	SAFE MARINE DEEPWATER RESERVOIR STAGE II REPORT	Report	1	7/7/2016
	TD-3226-521	SMT Stage II Project Management Plan Schedule	Schedule	0	10/8/2015
	TD-3226-523	SMT Stage II Canyon CONOPS FMECA	Spreadsheet	3	7/7/2016
	TD-3226-527	SMT Stage II Canyon Interface Control Document	Spreadsheet	0	7/7/2016
	TD-3226-528	SMT Stage II Canyon Compliance Matrix	Spreadsheet	0	7/7/2016
	TD-3226-529	SMT Stage II Canyon QRA Risk Reduction Spreadsheet	Spreadsheet	1	7/7/2016
	TD-3226-538	SMT Stage II Canyon CONOPS FMECA Pre-read	Report	2	7/7/2016

Drawings	CH104718	Diagram, Chemical Reservoir Deployment Methods	Drawing	0	7/7/2016
	CH104797	200bbl tank deployment	Drawing	0	7/7/2016
	CH104867	SMT Stage II Canyon Storyboard	Drawing	0	6/3/2016
Vendor Documents	N/A	SMT Concept Selection Report	Report	N/A	9/30/2014
	N/A	SMT Project Selection Report	Report	N/A	9/30/2014
	N/A	DSA-GRI-SMTSB Assessment	Assessment	C	10/29/2014
	N/A	DSA-GRI-SMTSB Benchmark Depth Analysis	Report	B	3/11/2015
	N/A	RA Spreadsheet 3-17-2015 rough data	Excel data	N/A	3/17/2015
	N/A	SMT's QRA Spreadsheet 3-18-2015 for review rev.B	Excel data	N/A	3/20/2015
	N/A	SMT's QRA Spreadsheet 3-18-2015 populated and colored rev.C	Excel data	N/A	3/24/2015
	N/A	Company 1 QRA Spreadsheet	Excel data	N/A	4/8/2015
	N/A	SMT C1055 Write-Up final (GRI Report)	Report	N/A	5/31/2016
	N/A	DSA-GRI-SMTSB-Benchmark Depth Analysis-Addendum	Report	N/A	5/18/2016